UNIVERSITY EXTENSION SERIES

EDITED BY J. E. SYMES, M.A.
Principal of University College, Nottingham

ELECTRICAL SCIENCE

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A MANUAL OF

ELECTRICAL SCIENCE

BY

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WITH THIRTY-NINE ILLUSTRATIONS

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CONTENTS

PREFACE

IN a small book on a large subject it is hard to know what to leave out. I have written, not for wealthy amateurs, nor for people who do not care to think, but for men and women who have to give up something else to spend a sovereign on their own education. Nearly all the apparatus described in this book can be made by any one with a few tools and a little finger-skill. Mere show-experiments have been omitted, and mainly those retained which serve to illustrate principles.

I have laid stress on the connection between

chemical action and current, because this can be easily studied; on the measurement of electricity, because it can be bought and sold; and on the relation of current to power, because that is the foundation of electrical engineering.

I have avoided all but the simplest formulæ, but have given data from which those who experiment for themselves may calculate the quantities and sizes of the wires, etc., required. Tables of Constants can only be original by virtue of research or of inaccuracy; mine are selected from the results of other people. I am especially indebted for suggestions as to convenient forms of tabulation to the works of Professor Ayrton, Professor Balfour Stewart, and Professor S. P. Thompson.

Some may complain that I have not used English

weights and measures. They will thank me in the end, if they continue to study science. A folding measure divided into *cms.* and *mms.* may be bought for threepence.

Sometimes I have employed a technical word before explaining the meaning of it. In such cases reference should be made to the Index, which is intended to serve as a dictionary of terms.

GEORGE J. BURCH.

OXFORD, 1893.

ELECTRICAL SCIENCE.

CHAPTER I.

FRICTIONAL ELECTRICITY.

Two facts concerning electricity were known to the Ancients as far back, at any rate, as Thales, 600 B.C., namely, that amber, when rubbed, has the power of attracting light bodies to itself, and that a certain mineral, known as the Heraclean stone or magnet, can attract not all bodies indiscriminately, but only iron. This knowledge, according to the Chinese historians, was possessed by their nation at a much earlier date, and even utilised by them in the form of the compass for directing journeys overland—they speak of an instrument which served to indicate the south. But in the West these two isolated facts remained for the speculation of the curious till about the twelfth century. No one knows who invented it, but there are references in certain early French songs, showing that the compass was in use about that date. Apparently they did not magnetise their

needles permanently, but rubbed them on the lodestone, just before they were wanted, and then balanced them on points, or floated them in a basin of water, to find the north and south. Somewhat later they appear to have added a cross index made of straw to point east and west.

Tradition at one time assigned the honour of introducing the compass into Europe to Marco Polo, about 1260, but it seems to have been known in Sweden ten years earlier, and the French songs already referred to existed at least a century before. Probably its introduction may have taken place at different times in different countries.

This was the first great practical application of one form of electric science, and here the matter rested till Gilbert, about 1600, wrote his celebrated treatise, "De Magnete." He showed that the power of attracting light bodies after being excited by friction is possessed by other substances besides amber, and gave it the name of "electricity," from *élektron*, the Greek for amber.

From that time men began to study the phenomenon. Otto von Guericke constructed an electrical machine consisting of a globe of sulphur mounted on a revolving axis and rubbed by the operator's hand. Isaac Newton and Boyle made a number of experiments, using glass instead of sulphur. The need of a machine to generate electricity in quantity was strongly felt, and much attention given to its development.

Resin was substituted for sulphur, and finally Hawksbee about 1713 replaced resin with glass. Hitherto the globe or cylinder had been rubbed with the hand and the sparks taken directly from it, but about 1740 Winckler introduced cushions stuffed with horse-hair and covered with silk, to give the necessary friction, and Bose used a metal cylinder

called the prime conductor, suspended by silken cords and furnished with a brush, or bundle of wires at the end nearest the revolving globe, to collect the electricity.

Ramsden, in 1760, replaced the cylinder by a disc of glass—and thus originated the "plate" machine, in use until the introduction of the Wimshurst, of which more anon.

Nairne, in 1774, devised the plan of insulating the rubber and putting it in connection with a metal cylinder like the prime conductor, so as to obtain negative as well as positive charges. (Fig. 1).

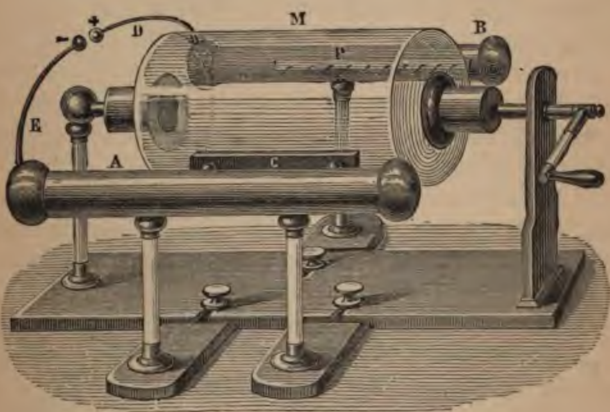


FIG. 1.

We will now suspend our historic sketch in order to describe some of the phenomena which were studied with the aid of these primitive appliances—for they are at present completely superseded.

We will suppose the student to be furnished with a glass tube—a piece of rabbit's fur, or cat's skin, or a silk handkerchief, for a "rubber"—a stick of sealing-wax or ebonite (a comb will serve)—some silk thread, and some elder pith. Everything must be thoroughly dried and warmed before a good fire.

(1) Cut off two pieces of elder pith (which is used on account of its lightness) and trim them with a sharp knife into little balls. Then hang them side by side on the ends of two fine silk fibres—ravellings will do very well. Rub the hot glass tube with the silk handkerchief or fur previously well warmed. Present it to a few tiny fragments of paper. They will be attracted. Hold it near the suspended pith balls; they also will be attracted at first, but as soon as they are charged with electricity, they will be repelled, and on withdrawing the excited tube will be found to repel each other for some time, causing the threads on which they hang to diverge.

(2) Repeat this experiment with cotton instead of silk. Unless it is extremely dry the pith balls will not diverge, because cotton is not nearly so good an *insulator* as silk, but allows the charge to escape.

(3) Rub the stick of sealing-wax, or the ebonite, with the silk, and present it to the pith balls. They will be attracted and then repelled, and will repel each other.

(4) Hold the excited glass tube to the pith balls charged by the electrified sealing-wax or ebonite and they will be instantly attracted by it. Electrify them afresh with the glass rod till it repels them and then present the excited stick of sealing-wax. It will attract them.

(5) Provide two pairs of pith balls suspended on silk threads, and hang them some distance apart. Electrify one

pair with the glass tube and the other with the sealing-wax or ebonite—then bring the second pair up to the first while they are still strongly repelling each other. The one pair will be at once attracted by the other, and all electrification will vanish the moment they are allowed to touch. From this we learn that electrification is of two kinds, that produced by glass being called positive and that due to sealing-wax or ebonite receiving the name of negative. And further we perceive that bodies not charged at all are attracted by electricity of either kind, but that two bodies charged with the same kind of electricity, whether positive or negative, repel each other, while if one is negative and the other positive, they are attracted.

Moreover, the experiment with the pith balls suspended by cotton threads showed that some substances allow the charge to escape, while others oppose an obstacle to its passage. The former are called conductors, and the latter non-conductors or insulators.

The following is a list of conductors, the best being placed first :—

The metals, carbon, the acids, aqueous solutions of salts, water, the bodies of animals and plants.

Substances which conduct with difficulty :—

Cotton, dry wood, dry paper. For weak currents this list includes perfectly pure water, and acids which contain no water.

Non-conductors, the best being placed last :—

Ice at—25C°, dry oxides, oils, porcelain, slate, and most kinds of stone. Sulphur, resin, gutta-percha, caoutchouc, shellac, paraffin, ebonite, glass, gases, air, and a *perfect* vacuum, but a partial vacuum allows high-tension electricity to pass with ease.

A block of solid paraffin is a splendid insulator. The student may easily make one by melting some good paraffin in a tin patty-pan placed on the hob, allowing it to set hard, and then placing it for a minute or two in a dish of boiling water until the block softens round the edges and can be turned out. It may be used to stand things on for electrification, instead of suspending them by silk threads.

With regard to the kind of electricity developed by friction, that depends on the nature of the bodies, both as to their composition and the character of the surface, whether smooth or rough. Whenever two bodies are rubbed together, one of them becomes positively, and the other negatively charged.

The following list of "*Electrics*" is partly taken from Stewart and Gee's "Elementary Practical Physics." Fur, glass, silk, the hand, wood, sulphur, wool, cotton, shellac, caoutchouc, and ebonite, resin, gutta-percha, metals, and gun cotton. If any two of these bodies are rubbed together, that which comes first in the list will become positively, and the other negatively electrified.

The following experiments are best made with an electrical machine, as they require larger quantities of electricity than can be readily obtained with tubes.

(6) Darken the room while rubbing the glass tube, or turning the machine. Flashes of light will be perceived, and sparks given off, which cause a slight pricking sensation when the hand is brought near the instrument. From the end of the prime conductor of the machine, a luminous appearance like a brush two or three inches long will be seen. This is due to the positive charge escaping into the air. If there is

also a conductor connected with the cushion, any points on its surface away from the rubber will seem to glow like stars. This is the appearance produced by positive electricity from the air entering the conductor, which has a negative charge. It should be noticed that the points on the prime conductor next the glass plate, where the positive charges enter it, are also tipped with tiny stars.

(7) Bring the knuckle near either conductor while the machine is turning; a spark will pass with a snap, but it is impossible to say which way it goes, whether to or from the hand.

(8) Fix a brass knob, such as the handle of a door, upright in a china candlestick, by filling the socket with melted paraffin, and holding the stem of the knob in it till it sets. This will insulate the metal ball. Now bring it near the prime conductor and work the machine; a few sparks will pass, and then no more. Present the knuckle to the knob—it will be found to give a spark. But having thereby lost its charge, more sparks from the prime conductor will go in, and charge it again.

(9) Fix a needle with a piece of gummed paper on to the side of the knob away from the conductor. The sparks will now enter continuously from the machine, but it will be impossible to charge the knob. The reason of this will be manifest in the dark. All the electricity flies off from the point into the air. It is on this principle that the lightning conductor protects a house. It draws off the electricity so fast that it is difficult for sufficient to accumulate to make a flash of lightning.

But we must return for a moment to an earlier period to describe an accidental discovery of the highest importance, involving a principle hitherto unknown. It was in 1745

that Von Kleist, Bishop of Pomerania, holding in his hand a glass bottle containing mercury, which he was trying to charge from the prime conductor of an electrical machine by means of a chain or metal conductor of some kind dipping down into it, happened to touch this conductor with his other hand. He instantly received a shock far more violent than that of the largest spark from his machine. The next year at Leyden, Musschenbroeck and one of his pupils named Cunæus were experimenting with the view of determining whether water, which is a conductor, could be electrified. One of them was holding a glass of water in his hand underneath the end of the prime conductor of the electrical machine, from which a chain hung down into the liquid. When he thought it sufficiently charged he attempted to remove the chain with his other hand, and instantly received a severe shock. Musschenbroeck, after trying the experiment himself, wrote to Réaumur saying that he would not willingly experience another for the whole kingdom of Europe. Thus was discovered one of the fundamental principles of electrical science. We have already seen that whenever two bodies are rubbed together one receives a positive and the other a negative charge—and it is in fact impossible to produce positive electricity without generating at the same time, on some other surface or surfaces in the neighbourhood, *an equal quantity* of negative electricity, and *vice versâ*. We have seen also that bodies charged with the same kind of electricity repel each other, whereas if one is negative and the other positive, they are attracted. Suppose now we charge *one surface of a body which is not a conductor*, what will happen to the other surface? It cannot be driven farther off, because to do so the material must be ruptured, and the force is

not great enough for that.[1] Instead, therefore, the influence of the charge tends to *drive off* an equal quantity of electricity of the opposite sign from the other side. Cunæus held the bottle in his hand. The positive charge came through the water and settled on the inner surface of the glass, but could not penetrate it. On the outside was his hand, which was a conductor, though of course not a very good one. Through his hand electricity from the outside of the bottle was driven off to earth, leaving it negatively charged. When he touched the wire in the water an electric current rushed from one side to the other through his body, causing the sensation that startled him. The reason why the shock was so severe was that much greater charges can be accumulated in this way, without tending to fly off. For imagine both sides charged positively or *vice versâ*. Each must tend to move away from the other, and as they cannot separate, the two charges will be under a repelling strain, and will therefore readily fly off. But if one side is positive and the other negative they will attract each other, being close together, so strongly as to neutralise the tension with regard to objects farther off.

This means of, as it were, storing up a charge enabled experimenters to study electric phenomena on a far larger scale. Water was soon discarded because the vapour rising from it speedily destroyed the insulation. Mercury was dear and inconveniently heavy, so at first the bottles were half-filled with shot. Finally the plan was adopted of lining them inside and out with tinfoil, leaving a clear space about the neck for insulation. A wire passing through a cork, with a chain on the lower end, and terminated above

[1] By means of the polariscope it can be shown that the material is actually strained.

by a metal ball, served to convey the electricity to the interior, while a chain in contact with the outer coating carried away the electricity driven off from it by *induction*, as it is called, to the ground or the rubber of the machine. This was the Leyden jar, known in its more modern form as the condenser.

To avoid the painful necessity of receiving the shocks through the body, an instrument was invented called the discharger. This, in its simplest form, is merely a stout brass wire, curved, with a knob at each end, and a handle—varnished wood does very well—in the middle. One knob is pressed against the outer coating of the jar and the other brought near the ball on the top of it. A spark passes with a loud snap and a brilliant flash.

It was soon proved that the charges reside, not on the metal coatings, but on the two surfaces of the glass itself. Perhaps the most brilliant, and certainly the more difficult, demonstration of this was given by Franklin who discovered it. He writes in 1748:—"The whole force of the bottle and power of giving a shock is in the glass itself, the non-electric in contact with the two surfaces serving only to *give* and to *receive* to and from the several parts of the glass.

"This was discovered here in the following manner." . . . (He first proves that it was neither in the wire nor the knob.) "Then to find if it was in the water we electrified the bottle again, and placing it on glass, drew out the wire and cork as before; then taking up the bottle we decanted all its water into an empty bottle, which likewise stood on glass, and taking up that other bottle we expected, if the force resided in the water, to find a shock from it, but there was none. We judged that it must either be lost on decanting or remain in the first bottle. The latter we found to be true

for that bottle on trial gave the shock, though filled up as it stood with fresh unelectrified water from a tea-pot."

Since only the contiguity of the two surfaces and not the shape of them is important, it occurred to Franklin to use a sheet of glass covered on both sides with tinfoil. The experiment succeeded, but he found that Smeaton had already invented this substitute for the Leyden jar. It is so much more compact and easy to construct and cheap, that the student should adopt it. Coat a good-sized pane of glass with photographic varnish, and when it is "tacky" lay on a sheet of tinfoil rounded at the corners and sufficiently smaller to leave a clear margin of at least one inch all round. Do the same for the other side, and when quite dry and hard, give it a couple of coats of French polish with a brush. To charge it, put one side in communication with the ground and let sparks from the prime conductor enter the other. To get a larger spark, a dozen or more of these plates may be piled on the top of each other, interleaved with sheets of plain glass varnished with French polish. To make the proper connections, build up the pile as follows:—

(1) Plain glass, with a strip four inches by one inch of tinfoil laid half on and half off the right hand end of it. (2) Coated plate with similar strip laid on the left hand end. (3) Plain glass, double the tinfoil of number one over number three and lay another strip on the top as before. (4) Coated plate, double tinfoil number two over number four and put a fresh one over it. (5) Plain glass, repeat as with number three, *ad lib.* The strips of tinfoil on the right hand connect the under sides of all the plates together, while those on the left join their upper coatings. The top plate of all, which is plain glass varnished, has a tinfoil strip

brought up on to it at each end and covered with the half of a pistol bullet to keep it down and serve as a discharging knob. This arrangement used to be called a battery of coated panes.

To send the discharge through any given substance it is best to set up the circuit beforehand; *e.g.*, two knitting-needles, each with a bullet stuck on one end, are arranged with their points on either side of a plate of glass, which should be thin. One bullet is connected with the negative side of the battery, and the discharger first touched against the other bullet and then brought round so that its other end comes near the positive knob. If the charge is strong enough it will perforate the glass. A lump of sugar will glow for some time after a strong discharge has passed through it. The spark from the conductor between two copper balls is green, and that between carbon poles is yellow, but ivory makes it red. In oxygen it appears white, in hydrogen reddish, in carbonic acid green, and in nitrogen blue or purple. To get a long spark from the battery, take the discharge over a strip of silver paper fifteen cms long. With a large battery it will pass through thirty or forty cms.[1] The metallic coating being too thin to conduct the electricity properly, its path is visible, and resembles a flash of forked lightning.

The Electrophorus.—We now come to another useful piece of apparatus involving the principle on which our most powerful generators of static charges depend. We have seen in the Leyden jar how when electricity is forced on to one side of it by the action of an electrical machine, it drives off an equal quantity of the same sign from the opposite side. In the electrophorus

[1] Cm = centimetre. See Appendix.

we have a charged body which is insulated, and we bring another body, not insulated, up to it. As in so doing we overcome the repulsion of the charge, we force it to drive off electricity from the other. If now we can cut off the connection of the second body with the ground, so that no more electricity can get to or from it, we shall find it to possess a charge, equal in amount, and opposite in sign, to that of the first body. But as the first body was insulated, none of its own charge could be lost, and it is ready to induce a fresh charge in the second body, if we repeat the previous operation, and so on *ad infinitum*, unless it leaks away in some other manner. The electrophorus, invented by Volta, may be made as follows. Fill a shallow patty-pan with melted paraffin, and let it harden. This is called the plate. Procure a disc of metal—the lid of a tin canister will answer—somewhat smaller than the surface of paraffin, and fix in the middle of it a handle of sealing-wax or varnished glass. To use the instrument, excite the paraffin by flacking it with a warm silk handkerchief or piece of fur, as it lies on the table. Then place the lid upon the plate, and touch it for a moment with the finger, in order that the charge upon the paraffin may be able to drive electricity off from the lid, and thus *induce* an opposite charge upon it. The lid is now attracted by the plate. Having removed the finger, and thus restored the insulation, lift the lid off the plate. In so doing you have overcome the attractive force, and will find that the plate will give a spark. This is a convenient way of procuring small charges of high intensity.

Almost from the first, attempts were made to design an electrophorus in which all these operations should be performed by the mere turning of a handle.

Nicholson's Revolving Doubler was the first machine of

this type, but owing to several defects, the remedy for which was perfectly simple, although, as usually happens, it was not perceived, it remained a mere toy, and was lost sight of. About 1865, Holtz, Bertsch, and others, produced machines on a similar principle, by which such enormous quantities of electricity could be generated, that the importance of the method was at once perceived. But they were uncertain in their action, and required to be separately excited, and it was reserved to Wimshurst, who combined the metal plates of Nicholson with the glass discs of Holtz's later type, to produce a machine which has practically superseded all others, for the production of what used to be called frictional electricity.

FIG. 2.

Two discs of glass or ebonite placed facing each other on one axle, are made to revolve rapidly in opposite directions

by a cord over a grooved wheel attached to each. These discs, which are varnished all over with shellac, bear on the faces away from each other a number of strips of tinfoil, like the spokes of a wheel, but not reaching the centre nor the edge, nor touching each other. On either side, at the level of the axle, are the collecting combs, which are bent round the edges of the two plates, but do not touch them. In front there is an insulated diagonal conductor, furnished at each end with a brush of fine wires, which touch the strips of tinfoil lightly as they fly past. At the back is another diagonal conductor exactly similar, but set at right angles to the first. A few seconds after the plates are set revolving, a crackling sound is heard, and a torrent of sparks passes continually between the knobs attached to the two collecting combs. A couple of small Leyden jars are fixed to the machine. When these are connected with the knobs, the sparks become intermittent, the interval between them increasing with the distance between the knobs. When these are several inches apart, each discharge is accompanied by a brilliant white flash, and a loud report. Small toy machines of this type may be bought for something less than a sovereign, which will do more work than a much larger friction machine. Each strip of tinfoil as it comes opposite each strip in succession on the other plate, forms with it a Leyden jar, so that if one should be electrified positively, the other is forced to assume a negative charge, if there is any conductor by which it can give off positive electricity. But as opposite charges attract, and like charges repel each other, in order to turn the machine, these attractions and repulsions must be overcome. The work thus done appears in the form of electricity. Conversely if we *supply electric charges* to a Wimshurst machine, these forces will *cause it to*

revolve. To show this, couple up the knobs of a large Wimshurst with those of a smaller one, taking off the cord so that it may turn freely. On working the first, the plates of the second will turn in the opposite direction. To trace the way it works, suppose the machine laid on its side with the plates horizontal, the top being North and the baseboard South. On the West is a collector, gathering electricity with its points from both plates, and leading it to one knob, and on the East is a similar collector receiving from both plates at once charges of the opposite kind. To get an easier conception of the action, let us agree to suppose that while a body is giving off positive electricity, a current is proceeding *from* it, and while it is negative, electricity is *flowing into* it. Further, let us assume that electricity flies off by the eastern comb, and on by the western. To complete the description we must remember that there is a diagonal conductor brushing against the top plate in the north-west, ready to carry electricity across, and deposit it on the tinfoil in the south-west, and a similar conductor below the bottom plate, ready to convey charges from the patches of tinfoil upon it in the north-east portion, and leave them upon whatever patches may pass over it in the north-west of the bottom plate.

Now trace what happens while the top plate revolves clockwise and the bottom plate counter-clockwise. Suppose that by some chance a patch on the bottom plate in the north-west is negative. The first patch on the top plate that passes over it will be touched by the brush of the diagonal conductor and instantly become positive by induction, drawing from the south-east section of the top plate, which will accordingly be left negative. The positive patch on the top plate passes on till it comes to the north-east.

Here the conditions are reversed. The top plate is touched by no conductor and cannot alter its positive condition, but the bottom plate comes against the brush of the other diagonal conductor, and becomes negative, depositing a positive charge on a section of the bottom plate in the south-west, and passing on to the north-west to induce a positive charge on one of the patches of tinfoil on the upper plate as it meets the brush. Meanwhile it must be remembered that the south-east of the upper plate was made negative by the first induction and remains so till it reaches the western comb, but before doing so, in passing above the brush in the south-west, draws from it on to the bottom plate a positive charge, which cannot get away till it reaches the eastern comb, towards which it is travelling. Thus if, to begin with, a patch on the bottom plate in the north-west is made negative, after a few turns every patch on the upper plate from north-west to south will be positive, and so will those on the under plate from south-west to south. At the south comb both plates lose their electricity, but directly they leave it the patches on each plate touch the brushes while passing by those portions of the opposite plate which have not yet reached the comb, and are therefore able to induce upon them negative charges, so that from south-east to west every patch on the upper plate is made negative, and so are all the sections of the lower plate from north-east to west. Thus every portion of both plates is negative as it comes west and positive as it approaches the east, and accordingly there is a continual discharge from one set of combs to the other. In practice there is always some trifling circumstance to cause a small charge on some one of the sections. This is rapidly increased by induction and communicated to the rest, until in a few moments the

machine is charged up, a rustling sound is heard, and the sparks begin to pass.

The *condensing electroscope* serves to detect feeble charges and is very easy to make. It was invented by Volta. A wide-mouthed bottle is filled with a stopper of solid paraffin, which may be a night-light with the wick drawn out. Through this passes a wire bearing on the top a metal disc —a penny will do, but it should be twice that size—thickly coated with shellac varnish. The bottom of the wire is bent horizontally to form a stirrup from which hang two strips of gold leaf face to face. On bringing an electrified body near the disc, the gold leaves will diverge. But the instrument is capable of much greater sensitiveness if rightly used. To show this, place the lid of the electrophorus (p. 12) on the disc, and touch it with the finger while the disc of the condensing electroscope is touched underneath by the body to be tested. Then lift off the lid by the insulated handle. If there was the slightest charge upon the body the gold leaves will instantly diverge. The reason is that the disc and the lid together acted as a condenser, or Leyden jar, the varnish on the disc preventing the lid from actually touching it, and the induced charge on the lid enabling the disc to receive a much larger quantity of electricity in proportion to its size from the charged body. The strength of a charge is called its potential. The quantity of electricity which an insulated body must receive in order to raise its potential from zero to unity is called its capacity. The capacity of two spheres is proportional to their radii. The capacity of a condenser depends on the area of the two surfaces, the nature of the substance between them (*i.e.*, its "specific inductive capacity"), and their distance apart. The closer they are together, the greater is the capacity.

A charge of electricity on a sphere is evenly distributed over its surface. But a charge upon a body of any other shape is not evenly distributed but collects most about its edges, angles, and points, or else in those parts of its surface near which there is some other body with a charge of opposite sign. The quantity of electricity collected in any part in proportion to the total charge is termed the *density* of the charge at that part. The distribution of charges was investigated by Faraday by means of a small disc of metal on the end of a rod of shellac. He touched this "proof plane" against different parts of the electrified body, and then, by bringing it to an electrometer, measured the strength of the charge it was able to bring away. He proved that electricity resides only on the surface by using a hollow metal ball insulated and charged. No charge could be taken away by touching it on the inside with the proof plane.

The law of electrical attraction and repulsion is like that of gravitation.

(1) The force of repulsion or attraction between two electrified bodies varies inversely with the square of the distance.

(2) At any given distance, the force of attraction or repulsion varies directly with the product of the quantities of electricity with which they are charged. This was shown by Coulomb with his "Torsion Balance." He used balls, because on them the charges are evenly distributed.

To illustrate the influence of the "specific inductive capacity" on a condenser, fix the lid of the electrophorus a short distance above the plate of the condensing electroscope, then charge the lid, and the gold leaf will diverge on account of the inductive action on the plate.

Now hold a sheet of glass between the plate and the lid, without touching either. The leaves will diverge more strongly, showing that the induction is increased. The effect will be greater with a plate of sulphur, or of shellac, or paraffin, and greater still with one of gutta-percha of the same thickness, because this substance has a higher specific inductive capacity than anything but mica.

CHAPTER II.

MAGNETISM.

THE natural magnet or lodestone (leading stone) is an ore of iron called magnetite, containing when pure three atoms of iron to every four atoms of oxygen. The name magnet is believed by some to be derived from a certain Magnes who discovered it, and by others, from Magnesia, also called Heraclea, a town in Lydia where it was first found. It is of an iron black colour when crystalline, and has the power of attracting iron, termed magnetism, and also of setting itself when free to move in a north and south position. This property is called polarity. When a piece of steel is rubbed upon a magnet it acquires and retains both these properties, and is then called a *magnet*, with the distinctive designation of *artificial*. Straight pieces of steel thus magnetised are called *bar magnets*, and U-shaped pieces *horse-shoe magnets*.

If a magnet is laid upon a heap of iron filings it will attract them and they will adhere firmly to it, not lying flat, but standing out on all sides like a brush. They will be most strongly held about the ends of the bar or horse-shoe, and scarcely at all by the middle of it. The ends of a magnet are called its poles, and the poles of a lodestone

can easily be found by dipping it in iron filings. Hard steel retains the magnetic power permanently, but soft steel soon loses it. Soft iron is only magnetic while in contact with another magnet. This is called magnetism by induction.

(1) Take a bar or horse-shoe magnet and hang it up by a thread from the middle. It will ultimately rest with its poles or ends lying nearly north and south; that pointing north is generally marked with a line or an N or painted red, and is called by most nations the north pole, but by the Chinese and French the south pole. To avoid the possibility of confusion it is now usually spoken of as the *north-seeking* pole.

(2) Now take a steel knitting-needle, and having marked one end with a piece of wax, place the middle of the needle against the middle of the magnet and draw it along as if sharpening a knife, so that the marked end of the needle is drawn across the north-seeking pole of the magnet. Repeat this several times and then suspend the needle horizontally. The marked end will turn towards *the south*, *i.e.*, its polarity is opposite to that of the pole which communicated the magnetic power to it. Bring the suspended needle near the hanging magnet. The north-seeking pole of the one will repel the same pole of the other, but opposite poles will be attracted.

(3) Harden another knitting-needle by making it red hot, and suddenly plunging it in a bucket of water. It will now be very brittle, and more difficult to magnetise. Having marked the north-seeking end, snap it in two, and suspend the pieces as before. Each fragment will be found to have two poles of equal strength, although there appeared to be very little magnetism in the middle of the needle before it was broken.

Bring the two ends together—they will attract each other, and while they are thus joined, will have very little power of holding iron filings, but it will at once return if they are separated, though only by a small distance. However many pieces the needle may be broken up into, each one of them will be found to possess a north and a south pole. This suggests the thought that in a magnet the molecules of the metal are possibly all arranged one way, like cards in a pack, so that the whole mass has similar properties to those of a single molecule. Of course, this is merely a hypothesis—that is to say, a sort of guess to account for some observed facts which we do not wholly understand. It is well to be chary about hypotheses, and yet it is almost impossible to do research without them. An experiment made without the object of testing some definite idea has been well called a "fool's experiment." The best plan is to try quite as honestly to disprove our hypotheses as to prove them. However, several simple experiments bearing on this one may be made.

(1) Fill a glass test tube with steel filings, and press them down with a cork; they may then be magnetised, just like a solid bar, and will attract iron, swing north and south, etc. Uncork the tube, pour out the filings, and then put them back again—the magnetism will be gone; you have disturbed the particles.

(2) Take a magnetised needle and hammer it. You disturb the molecules—it loses a great deal of its power. Make it red-hot, it loses all of it, for the heat disturbs the molecules. Place it while red-hot in a north and south direction, and let it cool; it will become magnetic, for while the molecules were settling themselves, they were in a position for the earth's magnetism to affect them. When a

piece of iron is made powerfully magnetic by induction, it becomes slightly longer, but does not increase in bulk. If rapidly magnetised and demagnetised many times in succession, it becomes hot. But there are many reasons for believing that heat is the evidence of a more rapid movement of the molecules; so that, on the whole, it is reasonable to suppose that in a magnet they must be arranged in some particular manner. The connection of magnetism with electric currents is discussed in Chapter V.

Other bodies besides iron are magnetic, but less strongly so; as for instance, nickel, cobalt, chromium, cerium, and manganese. The magnetism of nickel is very slightly affected by heat, whereas that of iron is not only completely lost at a red heat, but other magnets lose their power over it.

(3) Make a large nail or bolt red-hot all over, and hold it with a pair of brass tongs near a suspended magnetised needle. There will be no action whatever till the metal has cooled to a certain point, when it will quite suddenly be attracted.

Bodies which are attracted by a magnet are sometimes called paramagnetic, to distinguish them from certain other substances which appear to be repelled, and are therefore called diamagnetic. Bismuth, phosphorus, antimony, zinc, mercury, lead, copper, and gold are among the diamagnetic metals, and so is hydrogen gas.

But the power, even in the case of bismuth, is 400,000 times weaker than that of iron. Moreover, a solution of ferric chloride is magnetic, but if a weak solution is sealed up in a glass tube, and suspended in stronger solution of the same substance, it behaves as if diamagnetic, swinging east and west. So it is held by many that there is no true

diamagnetic polarity, but that the phenomena are, as it were, effects of contrast.

Terrestrial Magnetism.—The earth itself acts as a magnet, and that is why the compass needle points north and south. But since unlike poles attract each other, it follows that the magnetism of the north pole of the earth is of the same kind as that at the *south-seeking* pole of the compass.

(4) Carry a small compass round over a large bar magnet. When near the middle it will lie parallel to the magnet, but near the poles it will be deflected down towards them, the north-seeking end of the compass dipping towards the south-seeking end of the magnet and *vice versâ.* To show that the earth affects magnets in the same way, first carefully balance a non-magnetic knitting-needle and then magnetise it. It will no longer hang horizontally but, besides hanging north and south, will point downwards towards the north at an angle of about 67½° in these latitudes. This is called the *dip* or *inclination* of the compass. In 1600 A.D., it was about 72°.

The compass needle does not point to the north pole of the earth, but to what is called the magnetic pole, the position of which varies slowly. The deviation of the needle from the true North is called its *declination.* In the year 1580, it was 11° 36′ to the East. In 1663, the compass pointed true North, and after that began to deviate westward till in 1818 it was 24° 41′ West. Since then the declination has diminished, and in 1881 it was 18° 33 W.

The declination is, of course, different for each part of the world. It is in London greatest about the middle of March, and least at midsummer, but the variation does not exceed one-third of a degree. It changes also slightly during the day, but is fairly steady at night. During earth-

quakes and volcanic eruptions it is affected, and curious disturbances are sometimes noticed called magnetic storms. These are frequently associated with appearances of the aurora borealis.

The force of attraction and repulsion between two magnetic poles varies inversely as the square of the distance between them and directly as the product of their magnetic force. The reason why a suspended needle is not attracted bodily towards the north pole of the earth as it is towards a large bar magnet held near it, is that the earth is so large in comparison that the north-seeking pole of the largest bar magnet is practically no nearer the North than its south-seeking pole, and the one is just as much repelled as the other is attracted, or at any rate, our instruments cannot yet detect any difference.

Large magnets cannot be made so strong in proportion to their weight as small ones, and it has been shown by dissolving away a magnet in acids that the strongest magnetisation resides nearest the surface.

There are various ways of making magnets. That of single touch is best for compass needles, as it produces the most regular distribution of magnetism. Lay two magnets in a line in the magnetic meridian, far enough apart for the two ends of the piece of steel to be supported by their poles so as to form a bridge from one to the other. Next, take another pair of magnets, one in each hand, let them join together so as to form one long bar, and bring the junction down upon the middle of the piece of steel. Then separate the magnets, sliding them off at opposite ends of the bar, and sweeping out and upwards so as to bring them together at arm's length vertically over the steel. Bring the junction down again and repeat until the

magnet is strong enough. If too strong, turn it end for end, and operate as before, "taking off" touches until the needle is sufficiently demagnetised.

For the method of double touch arrange the magnetic bed as before, but use a horse-shoe magnet for the touch. Place both poles on the middle of the steel rod and slide them along to one end, then to the other and back again to the middle as many times as may be necessary, never stopping except at the middle, and at last lifting them off vertically. This method gives greater power but less regularity.

Steel may be made magnetic by placing it in a coil of wire through which a powerful current of electricity is passing.

It would take too much space to describe the method of measuring the absolute strength of a magnetic pole, but the relative strength of two magnets of exactly the same size and shape may be easily determined. Hang them up separately, and observe the time required by each to make a certain number of oscillations under the influence of the earth alone. From this calculate the number of oscillations which the stronger would make while the weaker oscillated one hundred times. Divide by one hundred, and the square root of the quotient is the relative strength of the two magnets. Thus, if one would make nine hundred vibrations while the other vibrated one hundred times, it would be three times as strong as the latter.

The Magnetic Field.—Just as a candle radiates light in all directions, with an intensity that diminishes as we recede from it, so a magnetic pole fills all space with an influence, sensible perhaps only in its immediate neighbourhood, but which still exists at any distance, however great. But it

differs from light in being apparently of two kinds, which counteract each other.

The effect of the north pole is the opposite of that of the south. Hence we cannot carry the comparison with light farther than saying that it radiates from the magnet as a whole, as light radiates from a candle. Bodies which are opaque to light are transparent to magnetic induction. Masses of iron alone check its passage, and they do this by acquiring induced magnetism of opposite polarity.

Strew some iron filings on a sheet of glass and fix it just above a magnet. Gently tap the glass so as to make it vibrate, and the filings will arrange themselves in regular lines and curves, following the direction of the "lines of force" of the magnetic field. The student should investigate their distribution.

(1) If a bar magnet is laid flat under the glass, the lines radiate like a fan from the two poles, where they are closer together, because the force is greatest there. Nearer the

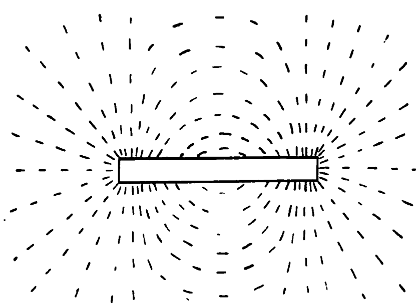


FIG. 3.

middle they bend over and unite, forming a series of arches.

(2) Place two bar magnets in a line, a little distance apart, under the glass plate, and by tapping it cause the filings to rearrange themselves. If the north pole of one is

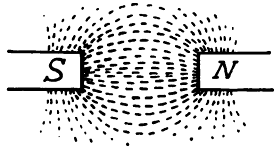


FIG. 4.

towards the south pole of the other, the lines will arch over the space as though it contained another very strong bar magnet.

(3) Reverse one of the magnets so as to bring two like poles near each other. The lines will now seem to bend

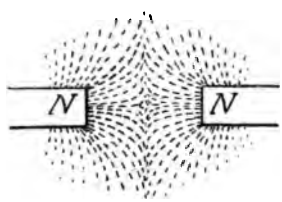


FIG. 5.

away at right angles, like the bristles of two soft brushes pressed together.

(4) Fix a round bar magnet—*e.g.*, a knitting-needle—in a vertical position and support the glass plate horizontally on its point. The lines will now radiate like the spokes of a wheel.

If we could ensure the regular distribution of the filings

in the first place, the closeness of the resulting lines at any part of the glass would be a measure of the intensity of the magnetic field in that place.

For instance, we might draw a pencil line through all the curves, so as to cut them wherever they were exactly one mm. apart. This would show the distance from the pole at which the magnetic induction was equal, for positions in front of the magnet or by its side.

Another line might be drawn cutting all the curves wherever they were two mms. apart. Here, supposing the vertical distribution to be the same as the horizontal, the force would only have one-fourth of the intensity, because the intensity is measured by the number of lines of force per unit area of radiation.

Such pencil lines would be called "lines of equal potential."

This subject will be further dealt with in the chapter on dynamos. Fig. 3 represents the horizontal lines round the poles of a bar magnet. Fig. 4 shows those about two unlike poles, and Fig. 5 represents the effect of reversing one of the magnets.

CHAPTER III.

CURRENT ELECTRICITY.

ELECTRICAL science had almost reached this stage, only that the theory of induction was in its infancy and influence machines were unknown, when a discovery was made leading to results which opened up a new branch of research. Galvani, Professor of Anatomy at Bologna, had been studying the physiology of the frog. It had been known for some time that when the nerve belonging to the leg of a frog is touched, even long after the creature is dead, the muscles contract. He had been investigating this phenomenon and had also been studying electricity. One of his pupils happened to try this experiment in the vicinity of an electrical machine they had been using. Probably there was some charge left in it, for as he touched the nerve the muscles moved more vigorously than usual. This attracted Galvani's notice, and one of the men—he does not say who, but it was a man—suggested that the electrical machine had something to do with it.[1] This was in 1780. Galvani

[1] In many books this suggestion is ascribed to "Madame Galvani." I trace this mistake to a French translation of Galvani's Latin account, in which the masculine word he used is rendered *une personne*. But she did help her husband in his work.

made a whole series of experiments, and got so far as to determine that a spark from the machine, without actually touching the nerve with the scalpel, would cause the leg to move.

Then, knowing that Franklin had proved lightning to be identical with electricity, he wished to try if it would have the same effect. There was a small lightning conductor fixed to the balcony of his house, and he hung the prepared muscle of a frog on to it by a copper wire touching the nerve. As may be supposed, he could not ensure favourable conditions at all times, and while he was waiting for a thunderstorm one day, it happened that the muscle touched the iron balcony and immediately contracted. It will be remembered that the nerve was in contact with copper. This was in 1786.

Galvani soon found he could produce this effect without the aid of lightning, whenever he had two different metals, one laid against the nerve, and the other on the muscle, and brought their free ends in contact.

His theory was that the contraction was caused by electricity generated by the animal tissues. He was partly right. Every nervous impulse and every movement of a muscle is accompanied by the generation of electricity, but the electricity which caused the movements in this case was generated by the metals themselves.

It fell to the lot of Volta to discover this and to give us the Voltaic, or as it is generally called in England, the galvanic battery. Volta had invented the condensing electroscope described on p. 18, by which he could detect very feeble charges. He had already found—and the student may repeat his experiment—that whenever two plates of different metals, such as copper and zinc, sup-

ported on glass rods, are placed together and then drawn apart, one of them is positively, and the other negatively, electrified. This was the clue he followed on learning what Galvani had done. Instead of touching two plates together *dry*, he wetted them with various liquids, notably salt and water, to imitate the natural moisture of the muscle and nerve. He found that thus arranged they were a continual source of electricity, the free ends showing a charge as long as the two metals were connected by the liquid, without touching each other. And so from point to point he was led on until he had produced his battery and his crown of cups, giving, not merely a charge of electricity, but a current strong enough to be felt.

The crown of cups is made as follows. Cut up a piece of thin sheet copper into strips of any convenient size—say one cm. by ten cms.—and provide an equal number of strips of sheet zinc. Solder them together by the ends in pairs and bend them into a ∩ shape, with one leg zinc and the other copper. Arrange a number of small glasses or cups in a circle open in front, and half fill them with brine. Place one of the bent strips with its zinc leg in the first glass on the left hand and its copper in the second. Put another with its zinc in No. 2 and its copper in No. 3, and so on, taking care that the copper always occupies the leading position round the circuit. If now one hand is dipped in the first glass and the other in the last, a shock will be felt, and again on lifting either hand out of the liquid. Even with seven or eight couples it may be detected, but with twenty or more it is very evident.

Volta invented another form of battery called "the pile." It consists of a large number of discs of zinc, copper, and felt, the latter being somewhat smaller, and made just

moist with salt water. They are piled up in the following order: zinc, felt, copper, zinc, felt, copper, etc., to the number of a hundred or more. Any one touching the top and bottom of the pile simultaneously will feel a smart shock.

Zamboni's Dry Pile is on the same principle. Take a number of sheets of so-called "silvered paper," and having slightly moistened them, coat the back of each with finely powdered black oxide of manganese, rubbing it on with a cork. Lay a number of sheets together, all the same side up, and cut them into discs with a large gun-wad punch. Pack a couple of thousands of these—still all the same way up—in a glass tube just big enough to hold them. To keep them in place, cork the tube at one end, and drop in a halfpenny on the cork. Then put in the discs, as many as it will hold. Lay another halfpenny on the top and press the second cork tightly on to it. To make the connections, drive a stout pin with a metal ball for a head through each cork till it touches the coin inside. Let the corks be driven well inside the tube, and fill up the ends of it with paraffin for insulation. Such a pile gives neither shock nor spark, because the quantity of electricity it generates is very small though its potential is high. But it can charge a Leyden jar if allowed a sufficient time.

The honour of this great discovery must be shared by these two men. If Galvani had not been studying together the physiology of nerve and muscle and the phenomena of electricity, Volta might never have thought of wetting his metal plates. But if Volta had not invented his condensing electroscope, there would have been no means of detecting the current produced by the two metals so as to show that it proceeded from them rather than from the animal tissue.

Volta announced his discovery of the "pile" in 1800. That same year Nicholson and Carlisle decomposed water by the current, and Davy produced the electric light. Seven years later the latter had discovered potassium and sodium with the large battery which he made for the Royal Institution.

Here our historic sketch must end, that we may discuss the modern developments of the science.

If a piece of clean zinc is put into a vessel containing sulphuric acid mixed with about ten times its weight of water, the metal is gradually dissolved, the solution grows warm, and a gas is given off, apparently from the surface of the zinc, in numerous bubbles. These bubbles may be collected by holding over them, underneath the surface of the liquid, an inverted test-tube previously completely filled with the dilute acid. The gas thus obtained is colourless, without taste or smell, and lighter than air. It burns with a pale blue flame, and when mixed with oxygen or air in the proper proportion and ignited, it explodes violently. On evaporating the liquid in which the zinc has been dissolved, crystals separate from it, although sulphuric acid by itself will not crystalise.

Chemical action has taken place in the following manner. The sulphuric acid, or, as it is more correctly termed, *hydrogen sulphate*, has exchanged its hydrogen for a corresponding quantity of zinc, forming *zinc sulphate*, and leaving hydrogen, which, being a gas, rose to the surface of the liquid in bubbles.

A little consideration will show that this rearrangement of the materials is not the only change that has taken place. Heat has been evolved in the same manner, though not to

the same degree, as when combustible bodies are burned, and it is evident that this heat, produced by what we may call the combustion of zinc in sulphuric acid, might serve as a source of energy, if it could be suitably applied. In other words, not only has one of the material products of the chemical change—the hydrogen—been wasted, but another product—the heat—has been dissipated also.

The experiment may be repeated in a modified form. Let there be placed in the dilute acid, side by side, a strip of copper and a strip of zinc. Then if the two metals do not touch, all will go on as in the previous case, but if they are brought in contact, the phenomena will be different: the zinc will dissolve more readily than before, and the bubbles which mark the exchange of hydrogen for zinc will be given off more freely, but they will arise, not from the surface of the zinc, but from that of the copper. It matters not whether the two metals touch beneath the liquid or above its surface, or whether they are connected by a long wire of copper, zinc, or any other metal; so long as there is a metallic as well as a liquid connection between them, the zinc dissolves, while hydrogen is given off from the copper, which remains clean, and is not acted on by the acid.

In this second experiment we have the same chemical action as in the first, only it is conducted in a much more perfect manner. The element which is entering into combination (zinc) is situated at one side of the vessel, and the element which it replaces (hydrogen) is evolved at the other side in contact with the plate of copper, and at the same time the molecular forces are so ordered and arranged that we are enabled to utilise the energy set free during the process in the form of an electric current, whereas otherwise it would be given off as heat, and wasted.

According to the atomic theory it is believed that all matter consists of extremely fine particles, so small as to be incapable of further division, and hence called *atoms*, which are, however, incapable of remaining separate, but go about combined in groups called *molecules*, or little heaps. In a simple element, such as hydrogen, or oxygen, or zinc, the atoms are believed to be combined in pairs, so that each hydrogen molecule consists of two hydrogen atoms, and each zinc molecule of two zinc atoms. But in compounds this is not necessarily the case. The atoms of some elements, such as hydrogen, sodium, and potassium, combine with those of certain other elements, such as chlorine, forming molecules, each of which contains one atom of chlorine united to one atom of hydrogen or sodium or potassium as the case may be. It is usual to designate an atom of any element by the initial letter of its Latin name, so that the molecule of hydrochloric acid or *hydrogen chloride* is represented by HCl, signifying that it consists of one atom of hydrogen joined to one atom of chlorine. Similarly the molecule of *sodium chloride* or common salt is written NaCl, because it is formed by the union of one atom of sodium (Na) with one atom of chlorine. Such elements are called monads.[1]

But there are other elements which require not less than two, three, or four atoms of such substances as hydrogen to combine with each of their atoms in order to form a molecule. Thus oxygen requires two, the simplest compound which it makes with hydrogen being *water*, the molecules of which consist of two atoms of hydrogen united to one of oxygen, thus, H—O—H, or, as it is written for brevity,

[1] See Table of Elements, p. 252.

H_2O. Oxygen and the elements which behave in this way are called dyads.

The element nitrogen combines with hydrogen in the proportion of one atom to three, forming H_3N, which is the symbol of *ammonia*. Such elements are termed triads. Carbon requires four atoms of hydrogen to form the compound H_4C or *marsh gas*, and is therefore spoken of as a tetrad.

A full explanation of the atomic theory is not within the scope of this book, but a brief sketch of it is given here to enable the student to understand the action of the chemicals in a galvanic battery. All chemical compounds consist of molecules, composed in each case of a definite number of atoms, arranged in a perfectly definite way. For instance, the sour taste of vinegar is due to the presence of a substance known popularly as acetic acid, and to chemists as *hydrogen acetate*. Each molecule of hydrogen acetate consists of eight atoms, namely :

Carbon - - - -	2 atoms.
Hydrogen - - -	4 atoms.
Oxygen - - - -	2 atoms.

Its "formula" is, therefore, $C_2H_4O_2$. Now the eight atoms forming each molecule are not huddled together anyhow, like the grains of earth and pebbles in a clod, but are linked together on a definite plan like the bars of iron in the girder of a bridge. The arrangement may be better understood by a diagram. Let each atom of carbon be represented by its initial letter, surrounded, as carbon is a tetrad, by four straight rods, which may be supposed to

possess a power of attraction like the poles of a magnet, thus :[1]

$$\begin{array}{c} | \\ -\mathrm{C}- \\ | \end{array}$$

Then as oxygen is a dyad, its atom will be :

$$-\mathrm{O}-$$

while hydrogen, which is a monad and can only hold one other similar atom, will be :

$$\mathrm{H}-$$

In order to satisfy the whole of the combining power and unite the eight atoms into a single molecule, we may arrange them thus :

$$\begin{array}{ccccccccc} & & \mathrm{H} & & \mathrm{O} & & & & \\ & & | & & \| & & & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{O} & - & \mathrm{H} \\ & & | & & & & & & \\ & & \mathrm{H} & & & & & & \end{array}$$

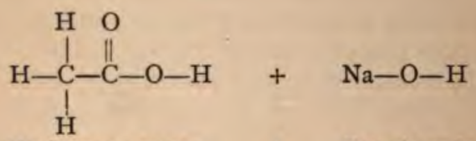
Here the two carbon atoms are linked together, leaving three out of the four "bonds" belonging to each free to attract other atoms. Three of the hydrogen atoms fix themselves to the first carbon, one of the oxygen atoms exerts the entire power of both its bonds in holding two of the bonds of the second carbon atom, while the other

[1] More precisely, they are not all in one plane, but are directed towards the four solid angles of a tetrahedron, of which the carbon occupies the centre. This does not affect the discussion of acetic acid, but must be taken into account in dealing with the tartaric acids.

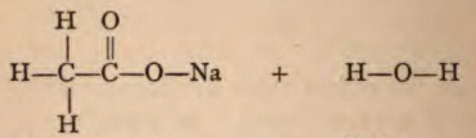
oxygen atom is linked on to the remaining bond, and at the same time has a place to offer to the fourth atom of hydrogen.

The constitution of acetic acid has been thus fully described, because it is simpler and better understood than those of the acids used in galvanic batteries. Like all acids, it has the power of combining with certain other bodies called "bases," and forming "salts" with them.

Thus acetic acid, or *hydrogen acetate*, unites with caustic soda to form sodium acetate, and setting free hydrogen. But as caustic soda consists of sodium, oxygen, and hydrogen, these latter elements unite with the hydrogen of the acetic acid, forming water, thus:



Hydrogen acetate + Caustic soda



Sodium acetate + Water

It will be seen that in this reaction sodium takes the place of hydrogen, but *only of that particular atom of hydrogen in each molecule which is linked on to the second atom of oxygen*, the remainder of the molecule being undisturbed. We might compare it to a fishing-rod, the owner of which puts on a new fly, replacing the old one in his book, but

does not alter the arrangement of the joints and tackle. The student should conceive every compound as consisting of vast numbers of molecules, each regularly built up of atoms in some such way as this, and exchanging certain of these atoms for the corresponding number of atoms of some other element, whenever a chemical change takes place.

But matter exists in three forms—solid, liquid, gaseous—and it is necessary briefly to refer to these. In solids, the molecules may be supposed to be practically in contact, so that they cannot easily slide past each other. In those cases where the substance has no particular structure, they are disposed irregularly, like bricks shot down in a heap. In crystals, they are arranged in regular rows and layers like the same bricks properly stacked. In liquids, the molecules do not quite touch, but are just far enough apart to slide freely past each other like shot in a basin. In gases, they are separated by a considerable distance, so that they can move freely. Roughly speaking, the molecules of H_2O in the steam inside a kettle of boiling water are about twelve times their own diameter apart; that is to say, if they could be so enormously magnified that each molecule would appear one inch in diameter, the average distance between any two of them would be a foot. A swarm of gnats dancing in the air upon a summer evening will convey a very good idea of the constitution of a gas.

Most of the substances we have to consider here are either in the liquid or gaseous state. Let us return to our first experiment—a piece of zinc dissolving in sulphuric acid, zinc atoms combining, hydrogen atoms driven off, energy set free, but without order, without direction, and consequently nothing but a struggle, resulting in the desired change, and the evolution of heat. In the second ex-

periment, in which a piece of another metal—copper—was also immersed in the acid and made to touch the zinc, we had the same chemical exchange, but it was effected in a more orderly manner; and the energy set free took the form of a current of electricity, rushing round and round through the liquid, and through the connecting wire.

CHAPTER IV.

BATTERIES.

For practical purposes, such forms of battery as have been hitherto described are useless. In the first place, they are wasteful, on account of what is called "local action," due to impurities in the zinc. Consider, for a moment, two tiny patches upon the surface of the zinc, differing in impurity either in degree or in kind; the one will act with regard to the other as though it were a different metal—it will not be attacked, but hydrogen will be given off from it, while the other is dissolved. The electric current thus generated will circulate, not by way of the wire, but merely through the two portions of the zinc, where it cannot be utilised, and the metal will be eaten into holes. This difficulty may be got over by "amalgamation." Mercury dissolves most metals just as water dissolves sugar, and as a crystal of barley-sugar dipped in water becomes sticky, so a piece of zinc rubbed with mercury becomes bright and pasty, owing to the superficial formation of an "amalgam" of mercury and zinc. The semi-fluid surface thus obtained is acted on with great regularity by the acid, and local action is reduced to a minimum.

The second objection is that the hydrogen collects in bubbles on the copper, and prevents the free access of the acid to it. Moreover, hydrogen, although a gas, is classed among the metals, and under such circumstances forms, as

it were, another galvanic battery with the copper, the current from which is in the opposite direction to that due to the zinc, which it partly neutralises. The first evil used to be got rid of by providing means for brushing off the bubbles, such as by blowing air through the liquid or keeping it in motion, or by making use of a rough surface from the minute angularities of which the bubbles easily escape. Both difficulties are avoided by introducing some chemical which can combine with the hydrogen as fast as it is set free.

To sum up. An ideally perfect battery should be portable, and not soon get out of order; it should give a steady current, strong in proportion to its size; there should be no fumes and no waste—*i.e.*, chemical action should cease when the circuit is broken; the positive metal should dissolve regularly so as to give a current as long as there is any of it left.

No one battery has all these properties, and in practical work something has to be sacrificed in order to secure that quality which is most important under the circumstances.

Daniell's Battery.[1]—A rod of zinc is placed inside a cylindrical pot made of some porous substance such as plaster-of-Paris or unglazed earthenware. A piece of sheet copper is bent into a cylinder rather larger than the porous pot, and placed in a glass jar, or well-glazed stoneware pot—the quart measures with handles, sold for about 3d. each, serving very well for this purpose. Dilute sulphuric acid (1:10) is poured into the porous pot so as to come within an inch of the top when the zinc is inserted, and it is then stood inside the copper cylinder. A solution of copper sulphate is poured into the

[1] Invented by J. F. Daniell, 1836. Becquerel had discovered the principle, but he used gold-beater's skin instead of the porous pot employed by Daniell.

outer vessel, and a good quantity of crystals of the same added, so as to maintain it at full strength. Binding screws attached to the zinc and copper serve to connect the wires for conveying the current where it may be wanted. When new zincs are used, they should be placed in the acid for a minute or two to clean them, and then taken out and rubbed over with a little mercury, using a small pad of tow moistened with the acid to spread it. This should be repeated as often as signs of irregular action are observed. Sometimes about 4 per cent. of mercury is mixed with the zinc of which the rods are cast. Even then, however, it is better occasionally to amalgamate them. If this is well done, no bubbles should be given off from the zinc while the circuit is open. But in practice about 3 or 4 per cent. of the current produced is wasted in local action.

After using, take out the zincs, wash them and stand them in a rack to dry; lift out the porous pots, empty the acid into the stock bottle, and keep the pots submerged in a vessel of water, otherwise they will crack owing to the crystallisation of zinc sulphate in the pores. The copper cylinders may be left in the outer vessels, together with the solution of sulphate of copper. Some inconvenience may be caused by the formation of crystals, which gradually creep up the sides of the vessel and over the edge. This may be prevented by smearing it for a distance of about an inch from the top with a mixture of vaseline and solid paraffin melted together.

The E.M.F.[1] is about 1·08 volts, but it is less when the battery is first set up, reaching the maximum in about an hour, after which it is fairly constant. The internal resistance[1] is usually about 2 ohms. Cost, from 2s. 9d. to

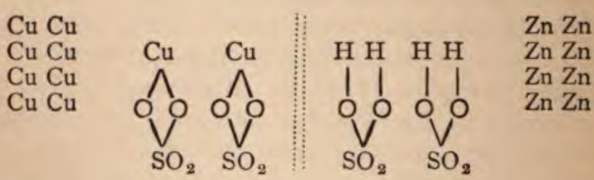
[1] These terms are explained on pp. 58, 108; 62, 77.

5s. 6d. They are useful in all cases where a steady current is required—*e.g.*, electrolysis, electrotyping, physiological experiments, and the study of the laws of currents and electro magnets, but not for producing the electric light.

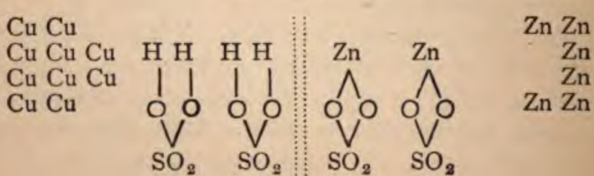
The chemical action is somewhat different from that which takes place in the simple zinc-copper cell already described. The student might be tempted to regard the saving of the dilute acid from the porous cells as a mere precaution of economy, but in reality the hydrogen sulphate only acts as a carrier, and will serve so long as the supply of copper and zinc, which are the real sources of the current, is kept up, and the excess of zinc sulphate removed from time to time.

The following diagrams represent the chemical action in two Daniell's, set up with hydrogen sulphate and zinc sulphate respectively.

Before the Action.

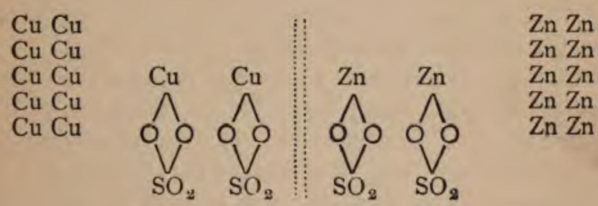


After the Action.

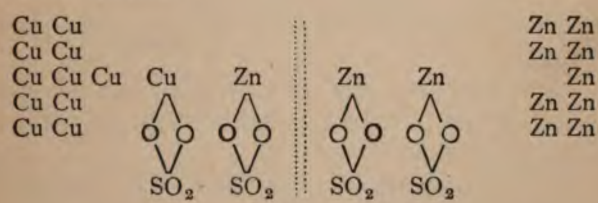


Here the copper sulphate is represented as being exhausted, and the combination is no longer a Daniell's battery, but a simple zinc-copper couple with sulphuric acid as the exciting fluid. As long as there was any copper sulphate left, zinc was dissolved on one side, and copper deposited on the other, the hydrogen sulphate merely serving as an intermediary. Now, however, it must act directly upon the zinc, and hydrogen will be given off from the copper until all the acid is exhausted.

A battery made up without any acid at all may be represented thus:



This will become:



And the action will continue as long as there is any copper sulphate left.

The object of the porous pot is to keep the two liquids from being mechanically mixed, and thus to ensure that no

zinc sulphate shall come in contact with the copper, and no copper sulphate shall touch the zinc. Copper sulphate forms a heavier solution than zinc sulphate, and several forms of battery have been devised in which advantage is taken of this fact. For instance, in Minotto's cell a sheet of copper lies flat on the bottom of a glass jar, having above it a layer of crystals of copper sulphate covered with a piece of canvas. On the top of this is a layer of sand or saw-dust covered again with canvas, on which rests a zinc plate furnished with a projection standing up out of the liquid, and carrying a binding screw. A stout insulated wire reaches down to the copper plate at the bottom, and the cell is filled up with zinc sulphate in solution. This form of battery is to some extent portable.

In the Callaud cell the canvas and the sand are omitted, and the zinc plate simply suspended near the top of a tall jar, which is then filled with water. The copper sulphate only dissolving slowly, very little reaches the zinc, and this may be prevented from damaging it by allowing the cell to send a feeble current through a high resistance, at any rate till it is "formed." Otherwise, long bunches of copper crystals grow like a fungus from the zinc, wasting it, besides lowering the E.M.F.

These cells need very little attention, and the current varies but slowly. But the resistance is high, and the current consequently small.

Moreover, they are not to be relied on as a standard of electro-motive force.

Leclanché Cell.—For some purposes a battery is required which can remain in readiness for use at any time without needing attention or wasting its stock of zinc. The Leclanché cell is best suited for electric bells, fire alarms, and

such experiments as can be completed in a short time, and in which constancy of current is not of primary importance. It is made in a number of forms, of which the following is the type.

The positive element is a rod of zinc, and the exciting fluid sal-ammoniac or ammonium chloride. The negative element is of a more complex character. A plate of carbon, such as is found in gas retorts, is placed inside a porous pot, and the surrounding space filled up with a mixture of manganese peroxide (the needle form) and small pieces of gas carbon. The whole is then immersed in the same solution of sal-ammoniac as the zinc. As the porous pot is only required to hold the manganese in position, it is dispensed with in some forms of Leclanché, the carbons being surrounded with a mixture containing 40°/° manganese dioxide, 52°/° carbon, 5°/° shellac, and 3°/° potassium disulphide, moulded by heat and pressure into a solid block.

Another kind has the zinc in the centre like a Daniell's cell, the carbon being a cylinder, inside which is a porous pot, the space between the cylinder and the pot being packed with manganese dioxide.

The action is somewhat as follows:

Ammonium chloride is NH_4Cl. and ammonia is NH_3. Now to make zinc chloride, we must have two atoms of chlorine for each atom of zinc. To do this two molecules of ammonium chloride must be decomposed, leaving eight atoms of hydrogen and two of nitrogen. The latter could hold six of the hydrogen atoms forming 2 (NH_3), and there would be two atoms of hydrogen left over. Manganese dioxide is MnO_2, but there is another compound, Mn_2O_3, containing two atoms of manganese to three atoms of oxygen.

Two molecules of the dioxide could therefore unite to form one molecule of this substance, and at the same time give up one atom of their oxygen to unite with the hydrogen set free. The actual reaction is, however, considered to be less simple. The E.M.F. is about 1·5 to 1·6, and the resistance from ·5 ohm to 1·5 ohm.

Dry Batteries.—Many of the so-called Dry Batteries belong to the Leclanché type. They are charged usually with some very deliquescent substance, and are sealed up. They are extremely portable, and last well, but have the disadvantage of all forms of Leclanché cell, *viz.*, the E.M.F. falls rapidly when they are put on short circuit. It soon recovers nearly its original value when no current passes.

We now come to the batteries generally used when a strong current is required, and constancy and economy are of secondary importance. They are the Grove, the Bunsen, and the Bichromate, or chromic acid cells.

Grove's Cell.—In Grove's cell the positive element is a plate of zinc immersed in dilute sulphuric acid, contained in a porous cell, which stands in a glass vessel filled with strong nitric acid. As in Volta's cell, the zinc is acted on by the hydrogen sulphate, each atom of the metal forming one molecule of zinc sulphate, and liberating two atoms of hydrogen on the side of the liquid which is in contact (through the pores of the porous cell) with the nitric acid.

The reaction which ensues is quite different from that familiarly associated in our minds with the word acid. Usually, on mixing an acid with a base, one particular atom of each molecule is turned out, and its place taken by the metal, the rest of the molecule remaining exactly as before (see *ante*, p. 40). Here, however, the entire molecule is

broken up and rearranged. It is generally stated that water and nitrogen peroxide, NO_2, a dark brown gas, are the products of the reaction, thus:

$$H + HNO_3 = H_2O + NO_2$$

But nitrogen peroxide is decomposed by water. If only a little water is present, and the temperature is low, the following reaction takes place:

$$H_2O + NO_2 + NO_2 = HNO_3 + HNO_2$$

i.e., two molecules of nitrogen peroxide and one of water form one molecule of nitric acid, HNO_3, and one molecule of nitrous acid, HNO_2.

At the ordinary temperature, if much water is present, the result is different:

$$NO_2 + NO_2 + NO_2 + H_2O = HNO_3 + HNO_3 + NO$$

That is to say, two-thirds of the nitrogen peroxide is made up into nitric acid, HNO_3, and the remainder given off as *nitric oxide*, NO, a *colourless gas* which has the property of uniting with oxygen directly it comes in contact with air, and forming dense brown fumes of nitrogen peroxide, NO_2.

Nitric oxide, NO, is also one of the ultimate products of the reaction first described. The nitrous acid formed at a low temperature is very unstable, and decomposes when warmed in the following way:

$$HNO_2 + HNO_2 + HNO_2 = HNO_3 + H_2O + NO + NO$$

On the other hand, if strong nitric acid is heated it begins to decompose at 86° C. into water, oxygen, and nitrogen peroxide, thus:

$$HNO_3 + HNO_3 = H_2O + NO_2 + NO_2 + O$$

And ordinary concentrated nitric acid owes its yellowish tinge to the nitrogen peroxide it contains.

Probably each of these reactions takes place in turn in the ordinary course of using a Grove's cell.

In his original paper,[1] Mr. W. R. Grove said: "If the operation of the battery be watched, the nitric acid, as we should expect, changes colour, assuming first a yellow, then a green, then a blue colour, and lastly becomes aqueous; after some time nitrous gas,[2] and ultimately hydrogen, are evolved from the surface of the platina." The author recently set up a small Grove cell in which the platinum was enclosed in an inverted glass tube completely filled with concentrated nitric acid, so as to collect the gases evolved. The experiment commenced at 5 p.m. By 7 p.m. the acid had become dark yellow—almost brown. There was no gas on the surface of the platinum, and only a tiny bubble in the upper part of the tube. At 11 p.m. the acid was green. The bubble had increased to the size of a small pea, but seemed to be colourless. At 8 a.m. on the following morning the acid was blue,—showing the presence of nitrous acid,—and the tube was full of a colourless gas which gave brown fumes when mixed with oxygen, and was evidently nitric oxide. It would appear, therefore, that nitrogen peroxide was first formed in solution, but that before there was a sufficient quantity for it to be given off as gas, another reaction set in by which nitrous acid and nitric oxide were produced. Possibly on a larger scale the action might be somewhat different. There are some reasons for supposing that nitrous acid is formed at once. The main point is that the E.M.F. resulting from the breaking up of the nitric acid molecule is *added* to that due to the solution of the zinc in the sulphuric acid, thus yielding a powerful current.

1 *Philosophical Magazine*, vol. xv., p. 290. 1839.

2 Priestley's name for nitric oxide.

The E.M.F. of Grove's cell is about 1·93 ohms, if the acid is fresh and has had time to soak into the porous pot. The resistance is very low.

The Bunsen Cell is like the Grove cell, but with a carbon block in place of the sheet of platinum. It is cheaper but more bulky, and the E.M.F. is a little lower. The chemical action is very nearly the same. Both these batteries should be placed in a draught cupboard when in use, as the fumes from them are very irritating and corrosive.

The Potash Bichromate Cell has an E.M.F. of about 2 volts, and a low internal resistance, so that it may be advantageously used to obtain strong currents, more especially as no fumes are given off. The E.M.F. falls off considerably after a short time of use, rising again when the battery is allowed to rest, and on this account it is not adapted for continuous work. There is, moreover, a good deal of local action, and cells of this type are generally made so that the zincs can be lifted out of the liquid when the current is not required. Some are constructed like the simple Volta cell, two plates of carbon being fixed a little distance apart in a glass bottle so as to leave room for the positive element, a plate of zinc, to be pushed down between them into the acid when the battery is in use. The exciting fluid is a mixture made as follows:

Bichromate of potash, 150 grammes.
Water, 1 litre.
Dissolve, and add slowly,
Strong sulphuric acid, 275 grammes.

Or else:

Chromic acid, 300 grammes.
Water, 1 litre.

If the battery is required for producing the electric light, about 50 cc. of strong sulphuric acid may be added.

Bichromate batteries are also built upon the type of the Daniell's cell, with a porous pot to contain the zinc immersed in either dilute sulphuric acid or a solution of common salt, the outer vessel, in which the carbons are placed, being filled with one or other of the mixtures already mentioned. In either case the action is much the same. When sulphuric acid is added to bichromate of potash, potassium sulphate is formed and chromium tri-oxide, $Cr\,O_3$, set free. This substance is now sold ready-made, under the name of chromic acid, and may be used for these batteries as has been already indicated, the object being to provide something to prevent the evolution of the hydrogen set free by the solution of the zinc in the sulphuric acid. This is effected in the following manner. The element, chromium, will unite with sulphuric acid much in the same way as zinc does, though not in such simple proportions. Two atoms of chromium can replace the hydrogen of three molecules of hydrogen sulphate, forming one molecule of chromium sulphate and setting free hydrogen. But inasmuch as in these batteries we use not chromium itself, but chromium tri-oxide, no less than six atoms of oxygen are liberated in the reaction, and this quantity is sufficient to combine with the hydrogen given off by the solution of the zinc as well, thus:

$$2\,Cr\,O_3 + 6\,H_2S\,O_4 + 3\,Zn$$
$$= Cr_2\,3\,(S\,O_4) + 3\,Zn\,S\,O_4 + 6\,H_2O$$

Smee's Battery was formerly much employed, especially for medical purposes. It consists usually of two plates of amalgamated zinc, immersed in dilute sulphuric acid, having the negative element, a plate of silver coated with finely divided platinum, between them. This battery approaches the original

Volta cell more nearly than any other, the chemical reaction consisting simply in the replacement of hydrogen by zinc. The slightly rough surface of the platinum causes the bubbles to rise more freely than they would from a plain copper surface, but in spite of this the E.M.F. falls off rapidly after a short time, and there is a good deal of local action.

Storage Cells are now largely used as a convenient source of electric current, but as these depend practically on a dynamo to charge them, they will be considered later on. The construction of standard cells will also be deferred until the chapter on Electrical Measurements.

Other means available for the production of currents are the various kinds of magneto-electric machines and dynamos, and for some purposes thermo-electric batteries are exceedingly useful. A description of these will be given after the principles on which they depend have been described.

CHAPTER V.

MEASUREMENT OF THE CURRENT.

LET us now turn our attention to the current produced by one of these batteries, taking for the purpose a Leclanché cell, in which the electrical phenomena are more striking, though the chemical action is not so simple as in the Daniell. On the upper end of the zinc rod is a binding screw or terminal, and there is a similar one secured to the carbon block. So long as these are not in any way connected, no chemical action takes place. On weighing the zinc rod, even after an interval of some weeks, it is found to have lost practically nothing. But if the terminals are connected by a copper wire, chemical action proceeds at once, and in a few hours the zinc will be found to have lost weight. A something which we call an electric current has passed along the wire. All substances will not serve equally to convey it. A glass rod, a piece of wood, a silk thread, or a dry string will not answer, and such materials are termed non-conductors. Metals transmit it most readily, then carbon and graphite, and lastly some liquids, especially solutions of acids in water, which, however, possess the quality in a far inferior degree. These are classed as conductors. Gases are non-conductors, and so is a vacuum *if perfect*, so that we have the anomaly that

whereas a current of water or of air will flow only when there is an empty space through which it can pass, a current of electricity will flow only when the space is bridged by a conducting material, and those which possess the power of conveying it most freely, *viz.*, silver and copper, are among the densest of the elements.

Yet in many ways a current of electricity resembles a current of water.

The question first arises, in which direction does it flow? Does it proceed from the zinc to the copper and stop there, or *vice versa?* Or does it go farther and come to rest in the salt of zinc formed by the solution of the metal? All we can say is that an electric current can be detected in the liquid, and that it is flowing from metal to metal in the opposite direction to that which it has in the wire, *i.e.*, that a battery may be compared to a pump drawing water from a tank and delivering it through a long range of pipes into the tank again. But which way the current flows we are unable to determine. Either hypothesis would explain the facts equally well, and so by common consent we say that the electric current proceeds *from the zinc*, or positive element, or metal which is dissolved, *through the liquid* or internal circuit, *to the copper*, or carbon, or negative element, or metal which is not dissolved, and thence *by way of the wire* or external circuit, *back to the zinc* again. Inasmuch as in all batteries in which there is evolution of hydrogen it is given off in contact with the negative element, it is easy to remember the conventional direction by considering that the current travels through the liquid with the hydrogen.

Which, then, is the *positive pole* of a battery? It is that end of the *negative element* which is *not* immersed in the

liquid. Great confusion of ideas is apt to arise if this distinction is not clearly grasped. An analogy may serve to fix it in the student's mind. Present the north-seeking end of a bar magnet to a compass needle; the effect produced is that due to the north-seeking end, but it is the south-seeking end which is held in the hand. So also that end of the zinc which is immersed in the acid is giving off positive electricity, and is therefore called the positive element, but the end above the liquid, to which the binding screw is attached, is in a condition to *receive* positive electricity from the wire, and is therefore termed the *negative pole* or terminal. Similarly the terminal on the copper is referred to as the *positive pole*, although the other end of the copper at which the hydrogen is given off is known as the *negative element.*

[*See* also the definition of "kathode" and "anode" in the chapter on Electrolysis.]

Following out the analogy between an electric current and a stream of water, we may observe that the quantity of water which can be delivered through a given pipe per minute depends on two things—the "head" or pressure of water and the dimensions of the pipe.

Similarly the quantity of electricity which passes per second through a given wire depends on the electric pressure, and the length, diameter, and quality of the wire. The electric pressure generated by a battery or dynamo is termed its electro-motive force or E.M.F. This is analogous to the total head of water at the pumping station of a water-works. But the available electric pressure in any particular portion of the circuit, which answers to the pressure of the water as it flows from the taps in the house, is spoken of

as "difference of potential," or, briefly, P.D., and this is always less than the total E.M.F.

Next with regard to the dimensions of the conductor. In the case of water, a 12-inch main will convey four times as much as a 6-inch main with the same velocity. This is evident when we reflect that, instead of a round pipe, we might employ a square trough covered in, and four troughs, each six inches wide and six inches deep, would be equivalent to a single trough twelve inches each way, except of course, that there would be more friction against the walls. This latter cause, however, does not come into effect in the case of such currents of electricity as are here dealt with, so that it may be said that if a certain quantity of electricity is conveyed by a given wire, one of double the diameter will transmit four times as much.

In scientific phraseology, the quantity of electricity flowing through a conductor varies directly with its sectional area. But a pipe is always measured by its internal diameter, no matter what may be the thickness of its walls. For instance, $\frac{1}{4}$-inch rubber tubing may measure no more than $\frac{3}{8}$ inch outside, but $\frac{1}{4}$-inch pressure tubing, the walls of which are half an inch thick, may be $1\frac{1}{4}$ inch through. In calculating the flow of water through a given range of pipes, if it were only possible to measure their external diameter, it would be necessary to specify the nature of each length of tubing, and, if we would be accurate, the character of each joint or stopcock, whether it afforded a free passage or not. Something similar obtains in the case of electricity. There may be some resistance to the current at each contact or binding screw, and the various substances which make up the circuit have different powers of conduction. We can only measure the outside diameter of a wire, but know nothing

of its molecular structure or the mechanism by which electricity is transmitted along it, and therefore, in order to be able to calculate what dimensions to give to the various portions of a circuit, electricians have determined what is called the "specific resistance" of various substances. Thus, the specific resistance of iron is about six times as great as that of copper, so that it would require six iron wires side by side to transmit as much electricity as would pass through a single copper wire of the same diameter and length. Tables giving the specific resistance of various substances, and the resistance of some of the sizes of wire in use, will be found on pp. 254-257.

The quantity of electricity transmitted by a conductor depends also upon its length. Thus, a wire 1 metre long will allow twice as much electricity to flow through it under the same pressure in a given time as a similar wire 2 metres in length—that is to say, the conducting power of a wire *varies inversely as its length.* But it would be exceedingly inconvenient to take the conducting power as the basis of measurement, as it would involve the working of a sum in long division to determine the proper length for every piece of wire used. To avoid this difficulty, the plan has been adopted of measuring, not the quantity of current allowed to pass, but the "resistance" offered to its passage, on the understanding that if one wire transmits twice as much current under the same pressure as another wire, it is said to have half the resistance. If it can carry only half the current, it is because the resistance is doubled; if one-tenth, the resistance is increased tenfold.

From what has been said, it will be evident that for practical purposes three different classes of instrument will be required for measuring respectively electro-motive force,

current, and resistance. It will be shown that any two of these suffice for determining also the third.

To return to the analogy of the water. Usually the flow is registered by a meter through which the entire amount charged for passes. This answers to the direct measurement of current by a galvanometer, or by an ammeter placed in the circuit. But to work a lift or a hydraulic motor, it is not sufficient that the quantity of water supplied should be sufficient to fill the cylinder the requisite number of times, it must be delivered under pressure, the amount of which is shown by a pressure gauge. This corresponds to an electrometer or voltmeter,[1] and just as the pressure in a pipe is relieved to some extent by the opening of a tap, and is greatest with every outlet closed, so also the readings of an electrometer connected with the terminals of a battery are highest when the circuit is broken, and fall directly a current is allowed to pass. If a pipe bursts in frosty weather, as long as the crack is small the water spirts up with great force, and the height to which it rises is a measure of the pressure in the main. As the breach widens the fountain sinks lower and lower, and at last flows quietly, without appearing to come under any pressure at all until you attempt to hammer the pipe up. Similarly with an electric current—an electrometer registers highest when little or no quantity is escaping, because it measures "pressure" or difference of potential. But a galvanometer indicates how much electricity is passing, and consequently falls to zero when the current is shut off.

Some galvanometers, however, are constructed so as to serve as electrometers, in a way which will be explained later.

[1] *N.B.*—A *voltmeter* must not be confounded with a *voltameter*. Compare p. 132.

There is yet another way in which water is sold which may serve to illustrate the third class of electrical measurements.

A fixed rental is charged for the use of a tap of stipulated size because the maximum quantity capable of being delivered under a given pressure in the main, through an aperture of known dimensions, can be easily calculated. The "resistance" of the pipes and of the tap prevents a larger quantity from passing. In like manner if the "resistance" of a circuit is known, the quantity of electricity which will pass through it under a given difference of potential can be accurately determined. To sum up, electrical measurements are of three kinds—current, electro-motive force, and resistance; and the unit of current is the *ampere*, the unit of electro-motive force or potential difference is the *volt*, and the unit of resistance is the *ohm*.

Galvanometers. — Magnetise a sewing-needle by one of the methods already described, and suspend it horizontally by a fine silk fibre. It will point north and south like a compass needle. Place one of the cells already described close by on the east or west side, with its positive pole (terminal attached to the copper of a Daniell or the carbon of a Leclanché) towards the south and negative pole (the terminal of the zinc) towards the north. Fasten a wire (No. 20 or 22) about a metre long from one binding screw to the other so as to form an arch or bow. According to the definition given, the current will flow through the wire from south to north, parallel to the needle. Probably no visible effect will be produced, because the strength of the current is but small. Lay hold of the wire with both hands and bring it down close above the magnetic needle—still keeping it north and south—and

the north-seeking end of the needle will swing towards the left hand or west. Next shift the wire so that it may pass underneath the needle instead of above it, and the deflection will be to the east. Then reverse the battery so that the current may flow in the opposite direction—*viz.*, from north to south, and it will be found that the effect produced on the needle is also reversed. With the wire above it, the needle is turned towards the east, and when the wire passes below it the deflection is towards the west. Finally, having fixed the wire in any one of these positions, disconnect one end of it from the battery; the effect on the needle will immediately cease and it will settle down to the magnetic meridian, thus proving that the deflection is not due to the wire but to the current of electricity, for on merely touching the terminal with the wire the effect is instantly produced. This experiment was made by Hans Christian Oersted while lecturing in Copenhagen in 1819, and it was the first step towards the discovery of the relation between electricity and magnetism on which the great majority of the practical applications of the current depend.

Instead of a needle suspended by a fibre, a pocket compass, which may be bought for sixpence, will serve, but the wire should not be left in connection with both binding screws for many minutes together, or the battery will rapidly run down.

The student is now in a position to understand the construction of a galvanometer. Repeat the first experiment, using the compass instead of the needle. Bring the wire to some definite position, *e.g.*, as near the glass as is possible without touching it, and note how many points the needle is deflected. Then undo one end of the wire and coil up the middle of it so as to make a ring of say half-a-dozen

turns. Pass this over the compass so as nearly to touch the glass, keeping the coils vertical, and the effect will be considerably greater, for now the current passes six times over the needle in one direction and six times under it in the opposite direction, so that both the upper and the lower half of each coil will tend to deflect the needle from north to west. If the coils are not vertical the effect will be diminished, and it will cease altogether if they are horizontal.

Schweigger's Multiplier was invented a short time after Oersted's discovery, and is a simple galvanometer on this principle. It consists of a compass needle suspended or pivoted in the centre of a vertical coil of wire fixed in a frame and furnished with binding screws, so that any current which it is desired to measure may be sent through it. The needle is provided with an index and a scale of degrees on which the deflection may be measured.

Such instruments serve to show the existence and direction of a current, but not to measure it in the true sense of the word. That is to say, if a certain current produces a deflection of ten degrees, it does not follow that one of twenty degrees will be caused by a current twice as strong. For both practical and scientific purposes it is necessary to be able to compare the readings of one galvanometer readily with those of another.

The Tangent Galvanometer.—This is the simplest form of instrument which fulfills the above requirements, and it can be made by anyone possessing a moderate amount of mechanical skill.

Having procured a small hoop, such as are sold in toy shops, say twenty-five cms. in diameter, wind round it ten turns of No. 20 covered wire, binding it at intervals with

silk or thread to keep the coils in place. Fix this vertically on a board fastened by a single screw in the middle, so that it can be turned round, upon another board provided with three levelling screws, and connect each end of the wire to a terminal. Having magnetised a piece of a sewing needle, not more than two cms long, thrust it through a small piece of cork, on the bottom of which, at right angles to the needle, a light straw is fastened with wax to act as an index. The straw may be from ten to twenty cms long. A loop of thread, or better, of very fine copper wire, may then be attached to the needle, and a single fibre of unspun silk tied to the middle of this will serve to suspend the whole so that the needle may hang horizontally exactly in the centre of the coil. It remains to provide a scale on which to measure the deflections.

Draw a circle on cardboard with a radius of ten cms, and bisect it with a line passing through the centre. Where this diameter cuts the circle, draw two lines exactly at right angles to it, and divide each of them into millimetres; then, with a straight edge, rule a line from each division passing through the centre of the circle to the corresponding one on the opposite side. This is called a "tangent scale," and must be fixed with the centre of the circle exactly under the centre of the needle and as close as possible to the index. With such a galvanometer the strength of the current will be directly proportional to the deflections of the needle measured on the tangent scale. It is suitable for use with moderately large currents, such as those given by ordinary batteries through short wires. Unless the needle and index are protected from the action of draughts, such galvanometer is, however, difficult to work with, and moreover, the oscillations of the needle are slow, making obser-

brass stop, so as not to touch it. In making an experiment, one of the battery wires is connected directly with the galvanometer, and the other is joined to the binding-screw on the left, and from that on the right a wire leads to the remaining terminal of the galvanometer. Thus although everything is ready, no current passes, but on pressing the strip of brass firmly down, the circuit is completed and the needle is deflected. This arrangement enables the observer to obviate the difficulty of the swinging of the needle. Instead of holding the key down continuously, he gives it a short tap, letting it rise as the needle starts and making another contact when it has got say half-way back to zero. The second swing is not so rapid. A third touch checks it again on the return, this time nearer the mark, and the resulting outward movement is still more gentle, till after repeating the process several times the key may be held down continuously with the needle quite steady at its full deflection, and the reading taken. With a little practice it is easy in this way to get rid of all oscillation. A button is provided to hold the key down when a continuous current is required. A piece of ebonite is fastened to the end of the spring to prevent the finger from touching the metal. For accurate work a little cup of mercury is substituted for the brass stop, and the end of the spring bent down so as to dip into the mercury when depressed. This makes a better passage for the current than the mere contact of two pieces of metal, which are liable to become tarnished.

Galvanometers for the measurement of very small currents are somewhat different in the details. As we have seen (p. 62), the nearer the wire is to the magnet, the greater is the deflection, and moreover, increasing the number of

coils increases the effect, each turn of the wire acting as though it were independent of the rest.

We may get greater sensitiveness by increasing the number of turns. But in this case the outside coils must necessarily be farther away from the needle, and have less effect. The lateral coils also must be in a less favourable position than those in the centre. Moreover if we use finer wire so as to bring a greater number of turns close to the needle, we increase the resistance and reduce the quantity of electricity that can flow through. In dealing therefore with large currents of feeble intensity, it is better to use a coil made of a few turns of thick wire, whereas with small currents of great intensity it is advantageous to have as many turns as possible. Such a galvanometer will respond to the movement of an electrified glass rod in its vicinity, whereas one having only a few coils would not be affected by it. Again, if the current to be measured has already passed through a great length of wire—or through some substance which is not a good conductor—the additional resistance of a large number of turns on the galvanometer will not reduce it so much.

For instance, suppose that each coil of wire has a resistance of one ohm, and that the battery resistance is one ohm also. Then the current with the galvanometer in circuit will be half what it would be through the battery alone. But if the resistance of the battery and of the rest of the circuit could not be made less than ten ohms, we might have ten turns of wire round the galvanometer, and get ten times the effect, and still only reduce the current to one half its full available strength.

The sensitiveness may also be increased in other ways. The action of the earth's magnetism tends to pull the

needle into the magnetic meridian as though its two ends were attached to threads running north and south. The current pushes the poles away at right angles from the wire —or we may imagine them drawn away by threads lying east and west. In proportion as the needle is forced away from zero, the north-and-south pull has greater power over it, just as a man riding a bicycle can exert his strength to better advantage when the crank is at right angles to the pressure. But meanwhile the position becomes less and less favourable to the east-and-west push, exerted by the current in the coils. Accordingly, in the same way as a spring balance is stretched out to some definite extent by a weight hung on it, so the needle is pushed aside to a definite angle, and if the coil is large in proportion to the needle, so that the distance of its two ends from the wire is not appreciably less in its new position, then *the tangent of the angle of deflection is directly proportional to the strength of the current.*

But we can increase the range of a spring balance by using a weaker spring, and we can make a galvanometer more sensitive by reducing the strength of the magnetic field. This may be easily shown.

Lay the pocket compass on the table and set the needle swinging. Note how rapidly it oscillates. Hold over it a horse-shoe magnet with its north-seeking pole towards the north. At a certain distance its influence will overpower that of the earth's magnetism, and the needle will swing round and point the reverse way. Raise the horse-shoe magnet a little, and a position will be found at which it will cause the needle to stand east and west. Fix the magnet so, and by moving a piece of iron near it, set the needle swinging. The oscillations are now very slow, but the iron need not be brought so near to produce them. Hold the

battery wire over the compass, and send a current through it—the deflection is very much greater than before, and is produced when the wire is some distance away.

The student may arrange a support for a horse-shoe magnet over his tangent galvanometer, which will then serve to detect very small currents, but as the controlling force is no longer solely due to the earth's magnetism, the instrument will now only give *comparative measurements.* But so long as the position of the controlling magnet is fixed, the tangent of the angle of deflection will still be proportional to the current.

This way of increasing the sensitiveness of a galvanometer is adopted in many instruments. In this case the coils have to stand east and west, not north and south. Another mode is to employ "astatic" needles. Two needles with their poles in opposite directions are hung, one just above the coil, and the other in the middle of it. They are rigidly connected so that one cannot swing without the other. The current through the upper part of the coil flows therefore *over* the lower needle and *under* the upper one. If the north-seeking end of the latter were towards the north, the effect would be to impel it in the opposite direction to the lower needle, but as the poles are reversed, the deflection of both needles is similar, and the two act together. That is one advantage. But besides this the controlling action of the earth affects them in opposite ways, so that if the two are exactly alike in power, and are set exactly in the same vertical plane, they will no longer seek the magnetic meridian, but will stand indifferently in any position. In practise these conditions are not quite fulfilled, and the "astatic" combination has a feeble tendency to an east-and-west direction. But although it

swings so slowly, the magnetic force of *each separate needle* is just as strong as ever. Hang it up in the centre of the coil of the tangent galvanometer—it does not answer so well as an ordinary needle—it is too sluggish. Raise it higher and higher alongside of the coil, and as soon as the upper needle is above the level of the wire, the combination seems suddenly endued with vigour—the smallest current makes it fly round to 90°. Raise it higher still, until both needles are above the coil, and once more it becomes sluggish. In Sir William Thomson's astatic galvanometer this principle is carried out still farther. Small pieces of steel can be magnetised more highly in comparison with their weight than large ones, and therefore instead of one needle he uses eight, four of which are cemented across one end of a strip of mica, and the remainder, with their poles the reverse way, similarly fastened several inches away near the other end of it. This forms the astatic combination, and is very light and stiff. It is suspended by a fine filament of unspun silk. There are four coils, a pair for the upper needles, and a pair for the lower group, and they are usually supported on a hinged frame, opening like the door of a cupboard, for the insertion of the astatic combination, and when this is in place closing upon it.

The upper pair of coils is of course wound in the opposite direction to the lower pair, in order, as the poles of the needles are reversed, that both sets may act together.

Another improvement consists in doing away with the long index. Instead of it a small mirror made of silvered glass, very thin, so as to weigh as little as possible, is attached to the magnet. The light of a lamp is thrown upon this by a lens, and reflected by it on to a screen, where

it forms a bright spot, the position of which changes as the mirror moves.

FIG. 7.

FIG. 8.

It must not be assumed that the deflections of this spot of light are directly proportional to the current, even supposing the galvanometer to indicate truly according to the tangent law. When the mirror turns through a given angle, the angle of incidence of the light is altered by the same amount. But by a well-known law of optics, the angle of reflection is equal to the angle of incidence, so that the reflected ray is moved through the sum of these two—*i.e.*,

twice the angle of the swing of the needle. Thus, the scale readings represent the tangent of an angle twice as great as the deflection. But we cannot take the half of these scale readings as representing the strength of the current, for twice the tangent of an angle is always less than the tangent of twice the angle, and the discrepancy increases with great rapidity as larger angles are taken.

Scale Reading with the Spot of Light. Radius = 1 Metre.	Error.	True Scale Reading with the Pointer.
100 mms.	$\frac{1}{4}$ mm.	$49\frac{1}{8}$ mms.
130 mms.	$\frac{1}{2}$ mm.	$64\frac{3}{4}$ mms.
160 mms.	1 mm.	$79\frac{1}{2}$ mms.
200 mms.	2 mms.	99 mms.
250 mms.	3 mms.	$123\frac{1}{2}$ mms.

Accordingly, for accurate work, unless the deflections are small, it is necessary to proceed as follows. In a table of natural tangents find the angle whose tangent is equal to the scale reading given by the spot of light, and *the tangent of half this angle* will be proportional to the current passing through the instrument.

The advantages of the mirror arrangement are, however, so great that it is used in all cases where precision is required.

Dead-beat Galvanometers.—It is important to check the oscillations of the needle, so that it may come rapidly to rest in any position. This is sometimes effected by attaching

to it a light vane of aluminium or mica, the movement of which is resisted by the friction of the air. In other cases the needles are enclosed in a hollow space just large enough to contain them in a solid block of copper placed in the centre of the coils. In this position the slightest movement of the needles causes currents to circulate in the metal in such a way as to exert a checking influence on them, and they accordingly swing just so far as they are impelled by the action of the coils outside and no farther —that is, if the mass of metal is great enough and near enough. Such a galvanometer is said to be "dead beat." The student will find it simpler to have a strip of parchment hanging from the needle and dipping into a vessel of raw linseed oil. This can be removed when damping is not required, *e.g.*, during experiments on induction.

Shunts.—A delicate instrument would be instantly spoilt if too strong a current were sent through it. For one thing, the needles would be thrown so violently against the stop as to damage them or break the silk on which they hang, and moreover their magnetism would be weakened or even reversed. It is necessary therefore to have some means of *decreasing* the sensitiveness of the galvanometer until it has been ascertained whether the current is such as it can bear with safety. Furthermore, it would be impossible accurately to measure the tangent of a large angle, and the instrumental errors would be very great. For this reason also, means must be provided by which a large current may be made to give a small deflection. This is effected by means of an instrument called shunt, which may be compared to the weir above a mill dam. By it a certain definite percentage of the current is allowed to pass without entering the galvanometer at all.

Both wires from the battery are joined to the shunt, and *both* wires from the galvanometer are also connected with it, so that there are two paths which the current may take, *viz.*, through the shunt or round by the galvanometer. A plug is provided which can be inserted into one of three holes. If it is placed in that marked $\frac{1}{999}$, then 999 parts of the current is taken across by the shunt, and only the thousandth part flows through the galvanometer. With the plug in the $\frac{1}{99}$ hole, the hundredth part, or in the $\frac{1}{9}$ hole, the tenth part of it is measured, and if the plug is not used at all, the entire current goes into the galvanometer. The arrangement of a shunt is shown in the diagram.

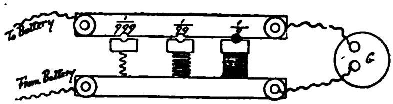


FIG. 9.

CHAPTER VI.

RESISTANCE.

Ohm's Law. $C = \frac{E}{R}$

The student is now in a position to investigate for himself some of the simpler problems of current measurement. In 1827, G. S. Ohm enunciated the law that bears his name. It is this: *The strength of the current is equal to the electromotive force divided by the resistance.* Now as the tangent galvanometer measures current, and the Daniell's cell has a fairly constant E.M.F., it is possible by means of these instruments to measure the resistance of a wire. Of course we must have some standard measure answering to the foot-rule of the carpenter, or the weights of the storekeeper. The unit of electrical resistance for commercial purposes is the Ohm, which is equivalent to a column of mercury 106 cms long, and one square millimetre section-area at the temperature of melting ice.

Coils of wire having a resistance of ten ohms are sold for about six shillings each. For rough purposes it may be taken that the resistance of 1788 mms. of No. 36 B.W.G. copper wire is one ohm, or the student may refer to the tables on pp. 251-255, and calculate from them what length to use of any wire he may chance to possess.

In the first place let us suppose the battery to be connected with the tangent galvanometer, and that the deflection is 250. Next disconnect one of the wires from the galvanometer and join it to one end of a wire having a resistance of 1 ohm, the other end being attached to the galvanometer, and observe the deflection. It will not be so great. Let us suppose it to be 200. Now insert also in the circuit a second wire of equal length and of the same gauge, having, therefore, a resistance of 1 ohm. The deflection will be about $166\frac{2}{3}$. But why is it not half what it was before, seeing that we are sending the current through a resistance of 2 ohms instead of 1 ohm? With 1 ohm it was 200, ought it not to be 100 when it passes through 2 ohms? The reason is that the resistance of the entire circuit must be taken into account. There is that of the wire forming the galvanometer coils, and the leads and connections. This can be calculated roughly if we know the length and size of wire employed. But there remains the *resistance of the battery itself.* The current has to pass from the zinc through a solution of zinc sulphate, a porous pot, and a solution of copper sulphate, to the copper. Have we sufficient data to calculate what this resistance must be from the deflections? By Ohm's law—

$$\frac{E}{R} = C.$$

With no resistance save that of the battery and galvanometer we found—

$$\frac{E}{R} = 250. \qquad (1)$$

With an additional resistance of 1 ohm we had—

$$\frac{E}{R + 1 \text{ ohm.}} = 200. \qquad (2)$$

From (1) we have—

$$E = 250\ R. \qquad (3)$$

and from (2)—

$$E = 200\ R + 200 \text{ ohms.} \qquad (4)$$

And as E is the same in both cases—

$$250\ R = 200\ R + 200 \text{ ohms.}$$

Therefore—

$$50\ R = 200 \text{ ohms.}$$

and—

$$R = 4 \text{ ohms.}$$

That is to say, the resistance of the battery and galvanometer, with the leads and binding screws, is 4 ohms.

If this calculation is correct, we shall obtain the same result from the deflection observed with a resistance of 2 ohms—

$$\frac{E}{R} = 250. \qquad (1)$$

$$\frac{E}{R + 2 \text{ ohms.}} = 166\tfrac{2}{3}. \qquad (2)$$

Proceeding as before, by (1)—

$$E = 250 \text{ R}. \qquad (3)$$

and by (2)—

$$E = 166\tfrac{2}{3} \text{ R} + 333\tfrac{1}{3} \text{ ohms}.$$

whence—

$$250 \text{ R} = 166\tfrac{2}{3} \text{ R} + 333\tfrac{1}{3} \text{ ohms}$$

Therefore—

$$83\tfrac{1}{3} \text{ R} = 333\tfrac{1}{3} \text{ ohms}.$$

and—

$$\text{R} = 4 \text{ ohms}.$$

That is to say, the two observations agree.[1] To find the resistance of the galvanometer, unless it is known already from the construction of it, we need a second galvanometer. For the sake of distinction let us call this B and the first A. Using B instead of A, an observation is taken of the maximum deflection given by the battery alone, and a second of the deflection when the current passes through 1 ohm resistance; from these data the resistance of the battery, *plus* galvanometer B, is calculated as before. Then the 1 ohm resistance is removed, and A put in its place. The current now passes through both galvanometers, but no

[1] It is instructive to repeat this set of experiments with a Leclanché. The results will probably *not* agree because the electro-motive force is not constant.

notice is taken of the movements of the needle of A—it is simply regarded as a resistance, and from the deflection of B the total resistance is determined. That of the battery, *plus* B, being already known, is subtracted from the result, and the remainder is the resistance of A.

Let us suppose this to be one ohm. Then as the resistance of the battery *plus* A was found to be four ohms, that of the battery alone must be three ohms, and this is about the usual "internal resistance" of a 3-pint gravity Daniell cell.

Other modes of measuring the resistance of a battery are given on pp. 97, 175.

The resistance of a wire varies directly as its length.

We may assume now that the resistance of the galvanometer and of the battery has been ascertained, and after the cell has been in action an hour or two it will be fairly constant, though it by no means follows that it will be quite the same the next time the battery is set up.

(1) Take a piece of wire ten metres long, and measure the resistance of it. Then undo one end and clamp the wire in the binding screw, so that only nine metres are in circuit. There is no need to cut it, but if it is insulated wire the covering must be scraped off the part held by the terminal. The resistance will be $\frac{9}{10}$ what it was before. Repeat the experiment with eight, seven, six, etc., metres in circuit. In each case the resistance will be proportional to the length used. It makes no difference if the wire is inserted in some other part of the circuit.

The resistance of a wire is inversely proportional to its sectional area (or to the square of its diameter).

(2) Take about four metres of No. 28 wire, and *exactly the same length* of No. 36, and measure the resistance of

each. No. 36 is about half the diameter of No. 28, and its resistance is rather more than four times as great. To measure the diameter, strip off the covering by singeing it, taking care not to melt the wire, and wind 100 turns of it round a pencil. Press the coils closely together and measure the space they occupy—divide this by 100 and you have the diameter of the wire. In this way 100 turns of No. 36 were found to take up 20 mms., and 100 turns of No. 28 occupied 40·6 mms. The resistance of the two wires was as

$$\frac{1}{20 \times 20} \text{ to } \frac{1}{4{\cdot}06 \times 40{\cdot}6}$$

or as 1624 to 400 nearly; so that No. 36, which is almost half the diameter of No. 28, has more than four times the resistance.

The resistance of a wire depends also upon the material of which it is made.

(3) Take a piece of German silver wire, of the same length as the wires used in the previous experiment, and if possible of the same diameter as one or other of them. Its resistance will prove to be about 13 times as great as that of a copper wire of equal dimensions.

(4) Next try a piece of iron wire such as is sold for making up flower decorations. Probably this will not be of the same diameter as the copper wire available for comparison. It will then afford an example of the way in which such problems are worked. Measure the diameter of the two wires in the way described. Call that of the copper a, and that of the iron b. Then, $\frac{1}{a^2} : \frac{1}{b^2}$: : resistance of the copper wire : resistance of a copper wire the same size as the iron wire. For example, suppose the diameter of the copper

wire is ·20 mm. and that of the iron wire is ·25 mm., and that the resistance of the length of copper wire taken is found to be 2·5 ohms, then, $\frac{1}{\cdot 20 \times \cdot 20} : \frac{1}{\cdot 25 \times \cdot 25} :: 2\cdot 5$ ohms : 1·6 ohms. That is to say, a copper wire of the same length, ·25 mm. in diameter, would have a resistance of 1·6 ohms. But the actual resistance of the iron wire will be about six times as great, *viz.*, 9·5 ohms.

Lead wire may be easily obtained. Its resistance is about twelve times that of copper. See Tables V. and VI. pp. 254-257.

Wheatstone's Bridge.—The method already given of measuring resistance is practically superseded by the use of Wheatstone's bridge, which is more accurate, and more convenient. When water flows freely through a long pipe, such as a garden hose with the rose taken off, the pressure is greatest where the water enters, and decreases regularly to nothing at the far end where it escapes. A small hole near the tap will emit a jet of water, a few drops will trickle from one about the middle, but nothing at all from a hole near the open end, because there is no pressure there. In the same way in a wire through which a current is passing, the electric pressure, or difference of potential between the two ends, decreases regularly from one to the other in proportion to the resistance through which it flows. If one portion is made up of thinner wire, there it decreases more rapidly, and where the wire is thicker the fall of potential is more gradual. Just as in a canal between two locks there is no stream unless the level of the water is lowered at one end or raised at the other by opening the sluices, so in a wire there can be no electric current unless the potential is higher at one end than it is at the other. Suppose two

wires, side by side, connected by their ends to the same battery so that each carries half the current, then, if we connect the middle of each wire to the galvanometer, the needle will remain stationary, showing that there is no current, because the electric pressure has fallen just as much in the one as in the other, and there is no difference of potential between the two points. Imagine now that one wire is coiled regularly so that the middle point can be easily found, and the other is lying loose. It is obvious that we can find the middle of it by sliding the connecting wire along till the galvanometer stands at zero. If we go too far one way there will be a current—if we come back beyond the middle there will be a deflection of the needle in the opposite direction, but when we reach the exact spot it will stand at zero.

If the connection with the galvanometer is made $\frac{1}{4}$th of its length from the end of one wire, then the neutral point on the other will be the same fraction of its length from the corresponding end, and so on.

But if the second wire is made up of pieces of different diameters, then the middle of its *length* will not have the same potential as the middle of the other wire. The neutral point will divide the wire not into equal lengths, but into two parts of equal resistance. There may be two paths down a hillside, the one steep and the other gently inclined. A hundred yards along the first may be halfway down, whereas the same distance along the second may be considerably above halfway. Or the slope of the second path may be irregular, but however much it may be so, the half of the descent is accomplished when a point is reached at which, if a ditch could be cut from one path to the other, water would lie in it without flowing either way, because

the two are on the same level. In the Wheatstone bridge the galvanometer is used as an electrical "level," simply to indicate when there is *no current*. The more sensitive it is the better, and it does not in the least affect the results whether the scale readings are proportional to the current or not.

The "bridge" may be made thus:

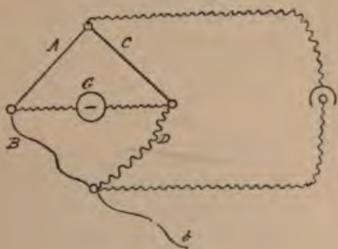


FIG. 10.

The two straight lines, A and C, represent two wires, the resistance of C and the length of A being known. They are both joined on to the end of one of the battery wires. D is the wire to be tested, and Bb is a long piece of the same gauge as A. The galvanometer G is connected with the junction of A with B and that of C with D. The other end of D joins the battery wire, and the long wire B is clamped in the same binding screw somewhere about the middle of it. Now if the resistance of D happens to just equal the resistance of C, then the *length* of B must be made equal to the *length* of A in order that there may be no flow of electricity through the galvanometer, which serves as a "level."

By loosening the binding screw, B may be easily length-

ened or shortened until the needle stands at zero. If the resistance of D is, let us say, twice as great as that of C, then B must be made twice as long as A to obtain a balance, and so on.

A simple piece of apparatus for measuring resistance in this way may be made by the student. In Fig. 11 *ab* is a

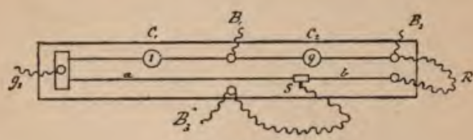


FIG. 11.

German silver wire 1 metre long, fine enough to have a resistance of at least 2 ohms. At one end it is fastened to the terminal g_1, and at the other to a piece of brass on which is the terminal g_2. On the board beneath it is a scale divided into millimetres. To the strip of brass is attached a wire leading to a coil c_1 of 1 ohm resistance, then a terminal B_1, past which it is carried to a coil C_2, the resistance of which, including that of the wire, is 9 ohms, and it ends at the terminal B_2. A slider S is laid on the wire *ab*. It consists of a piece of wood or ebonite weighted with lead and carrying a narrow strip of German silver across its under side. This strip is soldered to the wire leading to the terminal B_3. One of the wires from the battery is connected with B_3, and the other with either B_1 or B_2 according as a small or a large resistance is to be measured. The galvanometer wires are attached to G_1 and G_2 respectively. The resistance to be measured, R, is made to join G_1 with either B_1 or B_2; for example, suppose the latter. The current then enters at B_2, part of it

passing through the coils C_1 and C_2, which together have a resistance of 10 ohms, and thence along the wire *ab* to the slider S, by which it escapes to the terminal B_3 and thence to the battery.

The other part flows through the unknown resistance R to G_1, then along the wire *ba* to the slider S, and so by way of B_3 to the battery. Thus referring to the previous figure C_1 and C_2 together represent C, R takes the place of D, and that part of the wire *ab*, which is to the left of the slider S, corresponds to A, while the portion between S and G_1 corresponds to B.

FIG. 12.

The slider must now be moved along the wire *ab* until the needle of the galvanometer stands at zero.

Then the distance between S and G_2 is to the distance between S and G_1, as the resistance of the coils C_1 and C_2 (10 ohms) is to the resistance of R.

If the resistance of R is small, the coil C_2 may be left out, and the battery wire and the end of R attached to the terminal B_1. The proportion then will be

$$S\,G_2 : S\,G_1 :: 1 \text{ ohm} : R.$$

With this arrangement, resistances, varying from $\frac{1}{10}$ ohm to 100 ohms, may be determined with considerable accuracy.

For more delicate measurements it is better to use a Resistance Box, such as that represented in Fig. 12, p. 87. Here, instead of a wire with a slider to vary the resistance in the two halves of the second branch of the circuit, there is a number of coils, like a set of weights, with which any desired resistance from 1 ohm to 10,000 ohms can be made up.

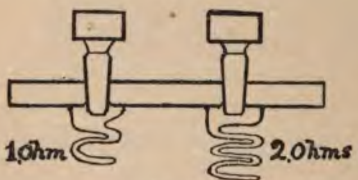


FIG. 13.

The ends of each coil are attached to solid blocks of brass, so that by inserting one of the metal plugs, shown in the figure, between any two of them, the corresponding coil is bridged over, and the current flows past without entering it.

Referring once more to the diagram Fig. 10, if with a resistance box like Fig. 12, we wish to measure a resistance

of, say, about 90,000 ohms, we may pull out the 100-ohm plug on branch A, and the 1,000-ohm plug on branch C. Then on branch B we remove the 5,000, 3,000, and 1,000 ohm plugs, close the battery circuit and depress the key of the galvanometer circuit for an instant. At this stage, as we do not know how far our estimate of the resistance may be wrong, we must employ the shunt, with the plug in the $\frac{1}{999}$ hole, so that only $\frac{1}{1000}$th of the current, if there should be any, may effect the galvanometer.

Probably there is a deflection. Pull out the 100-ohm plug and try again. The deflection is still greater, and we must use less than 9,000 ohms. Replace the 1,000-ohm plug and take out 500 and 300.

We have at present 5,000, 3,000, 500, 300, and 100, making 8,900 ohms in all. The deflection now is in the opposite direction, but on removing the 50-ohm plug, the needle appears to stand at zero. Leave the galvanometer key open and change the plug of the shunt from $\frac{1}{999}$ to $\frac{1}{99}$. With the increased sensitiveness there is a decided deflection showing that more resistance is wanted. Take out the 10-ohm plug, and there is now scarcely any deflection, so we put the plug of the shunt into the $\frac{1}{9}$ hole, and finding that the needle still barely moves we take it out altogether. The full power of the galvanometer is now in use, and on removing the 1-ohm plug, the needle stands at zero. It remains to count up the resistance of each branch of the circuit above and below the "bridge," *i.e.*, the galvanometer.

In A we have 100, and in B 5,000, 3,000, 500, 300, 100, 50, 10, 1, = 8,961 ohms.

In the other branch, C = 1,000 ohms, and D is unknown.

Therefore, 100 : 8,961 :: 1,000 : D.

Consequently D must be 89,610 ohms.

Using a galvanometer of high resistance, we may even make a further approximation. Suppose that with 8,961 ohms, the spot of light does not stand at zero but eight divisions from it on the scale, and that with 8,962 ohms, the deflection is 24 divisions in the opposite direction. Since a difference of 1 ohm produces a difference of $8 + 24 = 32$ divisions in the position of the needle, we estimate that 8,961 ohms is $\frac{8}{32} = \frac{1}{4}$ ohm too little.

It is a good exercise to make a resistance box—more especially as it is a very expensive instrument to buy. Use German silver wire, because it has a high resistance, which varies less with the temperature than that of copper, and is sold covered for the purpose. Ascertain roughly the length necessary for each coil, cut off somewhat more than is wanted, double it in half,[1] and wind it thus doubled on a bobbin, so that the ends come outside. Prepare the cover of the resistance box, fitting the brass blocks with their plugs in place, and drilling small holes for the ends of the wires. These may be wedged in temporarily with brass pins till the resistance of the coil has been adjusted, and then finally secured with solder. Resin must be used as a flux and *not soldering fluid*, on account of the danger of subsequent corrosion.

The first step is to buy or borrow a standard coil to work from. This should be of 100 ohms, unless two can be obtained, in which case one may be 10 ohms, and the other 1000 ohms. We will suppose that only a 100-ohm coil can be procured. Set up a Wheatstone's bridge according to the diagram Fig. 10, making the parts A, B, and C of

[1] This is to prevent the possibility of induction. See p. 176.

equal lengths of wire, and so that each may have a resistance of somewhere about 100 ohms. Use the 100-ohm coil for the branch D, and adjust the length of C till an *exact* balance is obtained with the full power of the galvanometer. Remember that it by no means follows that A equals B or that C equals D, the standard coil. Now remove D and put in its place one of the coils you have prepared. Its resistance is too high. Scrape off a little more of the covering and pull the wire farther through the hole in the brass block, loosening the wedge for the purpose until an exact balance is obtained, and then secure it with solder. Thus a copy of the standard coil may be made. When three such copies have been prepared they should be joined up into a new Wheatstone's bridge, using the standard coil for the fourth branch D. The accuracy of the work may now be tested by interchanging the branches thus: Put A in the place of B, and B in the place of A, and test. Then exchange D for C and C for D, and test again. If the deflection in each case is zero, the resistance of all four is exactly equal. Henceforth this Wheatstone's bridge must be used for making the remaining coils. We may proceed as follows. Keeping A = 100 and B = 100, make C = 200 by putting the standard coil and the third copy of it together. Place a coil containing about twice as much wire in the branch D, and adjust it as before till the galvanometer stands at zero. Its resistance will then be 200 ohms. Two coils of this size must be made. Next we proceed to 500 ohms by making C = 200 + 200 + 100, and balancing it with a still larger quantity of wire in D. Similarly we may go on to coils of 1000, 2000, and 5000 ohms. But it is time to proceed to the lower resistances, and for this we make up a new bridge in which A = 200,

B = 100, and C = 100 ohms. This will give D = 50 ohms.

Then putting A = 500, B = 100, and C = 100 ohms, we obtain D = 20 ohms. The ingenuity of the student will enable him easily to devise the method of making a coil of 10 ohms, and subsequently dividing it still farther, bearing in mind that the rule is A : B : : C : D where A, B, and C are known and D is the resistance sought.

It is well to note that the greatest accuracy is obtainable when the resistance of the one branch of the circuit A + B is most nearly equal to that of C + D. Too strong a current should not be used, otherwise the coils may become unequally heated and their relative resistance altered.

Variation of Resistance with Temperature.—Wind some fine covered copper wire on a stick or roll of paper so as to make a long narrow coil which can be inserted in a glass test tube. Stand this in a beaker of water or preferably of oil, in which a thermometer also can be placed. The beaker should be supported on a tripod, under which a lamp may be set so as to heat it. The two ends of the coil should be connected by *stout* copper wires with the Wheatstone's bridge. The resistance of the coil is then measured and the lamp lit. As the thermometer rises the resistance will be found to increase at the rate of about 1 per cent. for every $2\frac{1}{2}$ degrees Centigrade, but more rapidly at higher temperatures.

It must be noted that the coil will not be heated so quickly as the water, and the lamp should therefore be removed, and the water stirred and allowed to cool a little before taking a reading.

(2) Repeat the above experiment, using a coil of German silver wire instead of copper. The variation is now much

less, and a rise of nearly 23° C. is required before the resistance becomes 1 per cent. greater. For this reason German silver is used in making resistance coils.

(3) Test also the variation in the case of iron. A piece of bare iron wire may be pushed through a straw and the end wound round it in a spiral so that the coils do not touch each other. The resistance is about six times as great as that of copper and increases at the rate of 1 per cent. for every 2° C.

(4) Try whether liquids follow the same law.

As the composition of a liquid is altered by the passage of a current, a special arrangement is necessary.[1] We may use two pieces of copper dipping in a solution of copper sulphate, and then although copper will be dissolved off one of them, an equal quantity will be deposited on the other, so that the composition of the solution will remain unchanged.

Fix two stout copper wires in such a way that the distance between them cannot alter, and let them dip into a solution of copper sulphate in a beaker. Measure the resistance. If it is not great enough—say 10 ohms—put the wires farther apart. Warm the solution, and the resistance will be found to *decrease more than* 2¾ *per cent.* for a rise of temperature of 1 degree Centigrade.

(5) Repeat the experiment, using two strips of sheet zinc, dipping into a saturated solution of zinc sulphate in place of copper. On warming the liquid it will be found that the resistance decreases at the rate of about 2¼ per cent. for a rise of temperature of 1° C.

(6) Mercury is a liquid, therefore examine its behaviour in this respect. Take a piece of soft soda-glass tubing a

[1] See the chapter on Electrolysis.

few inches long, and hold the middle of it in the flame of an ordinary gas burner. When it softens remove it from the flame and draw the two ends apart. The soft part will stretch out into a fine tube, which may be made as small as the operator desires, according to the length to which it is extended. It should be big enough to take a needle.

Break it off near the tube at one end and bend the remainder into a U shape by bringing it *near* the flame till it softens. Great care must be taken not to melt it in doing so. Then fill it with mercury. This may be done either from the big end with a fine pipette, or better, by bending over the small end so that it can be dipped into mercury, and then filling it by suction. Push the large end through a hole in a cork in the side of which a notch is cut. Thrust a fine copper wire into the narrow end of the tube and bring it up through the notch in the cork, and then insert the whole in the test tube used in the preceding experiments. Make the connections with the Wheatstone's bridge by twisting the end of the fine wire round one of the leads and inserting the other lead in the large end of the tube so as to dip into the mercury.

Measure the resistance cold, put the lamp under the beaker and heat as before. The resistance will *increase* at the rate of about 1 per cent. for every 14° C.

Summary.

The resistance of *metals*, whether liquid or solid, *increases with increase of temperature.*

The resistance of *liquids* which are decomposed by the action of a current *decreases with increase of temperature.* The amount of the variation differs according to the nature of the conductor. (See also p. 214.)

CHAPTER VII.

ON THE BEST WAY OF COMBINING CELLS.

BEGINNERS frequently find that batteries will not do half the work they are said to be capable of performing. Very often this is because they are not properly arranged. Now that the methods of measuring current and resistance have been described, it may be useful to explain how batteries may be tested, and how several cells may best be combined for any given purpose. The current in *amperes*, generated by a battery, is measured by its E.M.F. in volts, divided by its resistance in ohms. Thus if the E.M.F. is one volt, and the resistance one ohm, then the current is one ampere. If such a battery is joined to a circuit having a resistance of one ohm, then the current will be

$$\frac{1 \text{ volt}}{1 \text{ ohm} + 1 \text{ ohm.}} = \tfrac{1}{2} \text{ ampere.}$$

A 3-pint Daniell cell may have an internal resistance of two ohms. Its E.M.F. is 1·08 volts. It would give through a resistance of one ohm in the external circuit,

$$\frac{1{\cdot}08}{2 + 1} = {\cdot}36 \text{ ampere.}$$

This would be a disadvantageous way of using it. Apart from the reason here discussed, with some batteries the E.M.F. would run down. A dry cell which gave 1·5 volts on short circuit at starting, gave only ·5 volts after eleven minutes. Suppose it were required to work a galvanometer. The greater the number of turns of wire in the coil, the greater would be the effect. But if we gave the external circuit twice as much resistance, we could double the number of coils, and the current would be

$$\frac{1 \cdot 08}{2 + 2} = \cdot 27 \text{ ampere,}$$

i.e., three-fourths of what it was, and this would give about as much effect as ·54 ampere flowing through the shorter coil. But it would not be possible to increase the number of convolutions indefinitely, because there would not be room for the wire without making the coil so large that the outer turns would produce very little effect, owing to their increased distance from the needle.

It is found that "to obtain the maximum magnetic effect with a galvanometer in a simple circuit, the gauge of wire wound on the coils of the galvanometer should be such as will make the resistance of the galvanometer equal to that of the rest of the circuit." [1]

And generally, when it is desired to obtain the *maximum effect regardless of the consumption of zinc*, the resistance of the external circuit should be equal to the internal resistance of the battery.

But in order to get the greatest amount of *work done in proportion to the weight of metal dissolved*, the resistance

[1] *Practical Electricity*, W. E. Ayrton, p. 135.

of the external circuit should be high in proportion to that of the battery. See on this point Chapter XIII.

The student should in the first place test his battery for resistance and current, as already described, with the tangent galvanometer, either assuming the E.M.F. to be that given in Chapter IV. for the particular form of cell employed, or testing it by one of the methods in Chapter VII. Frequently in home-made cells, especially of the Leclanché, or Bunsen, or Bichromate type, in which the negative element is carbon, the connection with the carbon is not good, and the resistance is very much greater than it should be. This must of course be remedied.

Another way of measuring the resistance of cells when several of the same kind are used, is to couple two together, joining zinc to zinc. The current from the one will thus neutralise that of the other, and their united resistance may be determined in the same way as that of a wire, and the resistance of each may be assumed to be half the total. This method is not accurate, as there may be a slight difference in the E.M.F. of each.

Mance's plan is to put the battery in the place of D in a Wheatstone's bridge, and where the battery is usually situated put a key by which the circuit can be closed or opened. The galvanometer will be deflected to a certain position on the scale. Note at what division it stands. Close the key, and if the needle moves, alter the resistance of B until the opening or closing of the circuit makes no difference to the deflection. Then A : B :: C : the resistance of the battery. This method is not reliable. [1]

Having ascertained that the cells are in good order, it remains to consider how best to combine them for any

[1] See also Kohlrausch's method, p. 175.

given purpose. Hitherto we have dealt with circuits containing only a single battery. There are three ways in which a number of cells may be joined to any given external circuit:

(1) Parallel, or abreast.

All the zincs are connected with one wire and all the coppers with the other.

(2) In series, or tandem.

The zinc of each cell is joined to the copper of the next, like the links of a chain, the copper of the first cell being united to one wire of the external circuit, and the zinc of the last cell to the other.

(3) Part in series and part parallel.

Here the cells are disposed in groups, each group consisting of the same number of cells in series, the zincs of all the groups being connected with one wire, and the coppers with the other of the external circuit.

It remains to examine for what purposes each arrangement is best fitted. Suppose it is required to raise a quantity of water, and a dozen 4-inch suction pumps are available for the purpose. It is a matter of common knowledge that the height to which a suction pump will lift water is limited. Practically it may be taken as about 25 feet. So also the E.M.F. of a Daniell's cell may be taken as roughly equal to one volt. Now if the height to which the water is to be raised is 25 feet *or under*, it will be done most quickly by setting all the pumps to work side by side, and then the quantity raised will be twelve times as much as would be lifted by a single pump, and the work will be completed in one-twelfth of the time.

If the height is anything between 25 and 50 feet, we must do it in two lifts. Six pumps may be set to deliver

into a tank half-way up from which the other six can draw. Between 50 and 75 feet, three stages would be required. In this case the pumps might be four abreast. From 75 to 100 feet we should need four lifts, and from 100 to 125 feet, five lifts, but in the latter case we could not profitably use more than ten pumps, as the number would not be sufficient to make three complete series, and if a larger number were set to work at any one stage, they would simply empty the tank below and cause the one above to overflow. Up to 150 feet we could arrange them in double sets, and beyond that, up to 300 feet, there would be no advantage in using them other than singly, each one delivering to the one above.

It is much the same with batteries. In order to deliver the same quantity of electricity in the same time through double the resistance, we must double the pressure, or difference of potential, between the two ends of the conductor. Just as each pump will raise a certain quantity of water about 25 feet, so each cell will give a certain quantity of electricity, according to its size, etc., at a certain "pressure" depending on its E.M.F. What we have to determine is the smallest number of cells that will give the requisite difference of potential, and then to consider how large each cell must be, or how many of a smaller size must be set working side by side, to afford sufficient current. When all the cells are in series, the total E.M.F. of the circuit is as many times the E.M.F. of one as there are cells in the series—that is, if they are all alike, otherwise it is simply the sum of all the electro-motive forces. But as the current has of necessity to pass through each cell in succession, the total resistance is the sum of all the resistances. Numbering the cells 1, 2, 3, 4, and calling the

resistance of the first R, and that of the second R_2, etc., and their electro-motive forces E_1, E_2, etc., respectively, the current given by the entire series will be

$$\frac{E_1 + E_2 + E_3 + E_4}{R_1 + R_2 + R_3 + R_4} = C$$

Or, supposing the cells all alike,

$$C = \frac{4\,E}{4\,R} = \frac{E}{R}$$

But if we arrange them in parallel, then the current of each will be produced separately, but they will all enter the wire of the external circuit together, just as the twelve pumps all delivered into the same trough side by side when the total lift was only 25 feet. In this case, the current *available* would be

$$C = \frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3} + \frac{E_4}{R_4}$$

And if all the cells are identical as to resistance and E.M.F., we have

$$C = 4 \times \frac{E}{R}$$

That is, the current is *the same in intensity* as that furnished by a single cell, only there is four times as much of it.

In the other case, with the cells *in series*, the current $C = \frac{4\,E}{4\,R}$ was *the same in quantity* as that given by a single cell, but it was four times as intense. But when the current has to pass, not merely through the cells, but through an external resistance in addition, the essential difference of the two systems is manifest. With four cells in parallel, the

total E.M.F. is that of a single cell, but as the electricity has four separate roads by which it can travel, the internal resistance is only $\frac{1}{4}$th of that of one cell. The current, therefore, is

$$C = \frac{E}{\frac{1}{4}R} \quad \text{or} \quad C = \frac{4\ E}{R}$$

If now we send it through a coil of wire having the same resistance as one of the cells, *viz.* R, we have

$$C = \frac{E}{\frac{1}{4}R + R} \quad \text{or} \quad C = \frac{4\ E}{5\ R}$$

That is to say, the current is now only one-fifth what it was.

Try the same cells in series: the total E.M.F. is now 4 E and the total resistance is 4 R. This gives for the current

$$C = \frac{4\ E}{4\ R} = \frac{E}{R}$$

Adding now the same external resistance as before, we have

$$C = \frac{4\ E}{4\ R + R} = \frac{4\ E}{5\ R}$$

i.e., the current is $\frac{4}{5}$ths of what it was without the external resistance. That is to say, if the apparatus we desire to use has a high resistance, we shall get more electricity through it in a given time by using a battery so arranged as to deliver the current at a high pressure.

The student may calculate the different amounts of current which would be given with various combinations of cells through the apparatus he possesses. He will find that the maximum effect is produced when *the total resistance of the battery is equal to the external resistance of the circuit.*

The best arrangement may be found by the following

formula :—Let N be the number of cells arranged in p rows contained s cells each, thus :

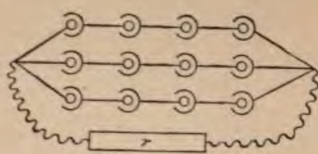


FIG. 14.

Here $p = 3$, and $s = 4$.

Each cell has an E.M.F. of E volts and an internal resistance of R ohms. The external resistance of the circuit represented by the wire r is r ohms. Then the total E.M.F. in circuit is $= s$ E volts.

And the total resistance in circuit is $= \frac{s\,R}{p}$ ohms $+\ r$ ohms. So that the current which passes is, by Ohm's law,

$$(1) \qquad \text{C amperes} = \frac{s\,E}{\frac{s\,R}{p} + r}$$

But the total number of cells N equals the number of rows multiplied by the number in each, or $N = s\,p$. So that (1) may be written

$$(2) \qquad \text{C amperes} = \frac{s\,E}{\frac{s^2\,R}{N} + r}$$

In the figure, $N = 12$, $s = 4$. Substituting these values, we have

$$C = \frac{4\,E}{\frac{16\,R}{12} + r} = \frac{12\,E}{4\,R + 3\,r}$$

Now it can be shown that whatever may be the value of E, the current C will be greatest if

$$(3) \qquad r = \frac{s^2 R}{N}$$

In the case we have taken, we must make

$$r = \frac{16 R}{12} = \tfrac{4}{3}R$$

That is to say, if the resistance of the external circuit is $\frac{4}{3}$ that of a single cell, then the best way of using 12 cells is to arrange them in three parallel rows of 4 in each series. But generally it is required to find the best arrangement to work *a given external resistance.* The formula (3) may be written

$$s^2 = \frac{r N}{R}$$

whence

$$s = \sqrt{\frac{r N}{R}}$$

i.e., multiply the external resistance by the total number of cells, and divide by the internal resistance of one cell. The square root of the quotient will be the best number of cells to put in series. Probably this will not be a whole number. In this case, find by calculation with the numbers above and below what current would be obtainable with either arrangement, and adopt that which gives the best result. See also the chapter on Electric Lighting.

CHAPTER VIII.

MEASUREMENT OF ELECTRO-MOTIVE FORCE.

PROBABLY most people have amused themselves by holding a finger over the end of a pipe from which water was flowing, and seeing how far they could make it spirt by partly closing the aperture. A very little consideration will show that the height to which such a jet will reach depends on the pressure in the main. But this pressure is only exerted to the full when the quantity of water allowed to escape is *small in comparison* with what the pipe could supply, running at full bore. It would even be possible roughly to estimate the "head" of water by measuring the height of a *small* jet issuing from the main. A somewhat similar mode of measuring, with far greater accuracy, is possible in the case of an electric current. For this purpose a galvanometer of high resistance—5000 or 6000 ohms—is employed. Such an instrument may of course be wound with a great number of turns of wire, and will accordingly be extremely sensitive, and capable of measuring such slight currents as are produced by a mere touch of the finger.

For instance, lay hold of the terminals of the galvanometer with the forefinger and thumb of the two hands, which should be first carefully washed and dried. By

gently tightening the grasp, first of one hand and then of the other, the needle may be made to move about at the will of the operator. Such a galvanometer would be ruined by sending through it the current even of a single cell; but by interposing a very high resistance between it and the battery, the current may be so much reduced as to be quite safe. The following simple form of variable graphite resistance may be made for use both with a sensitive galvanometer and the capillary electrometer.

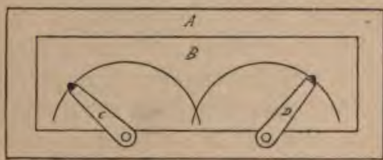


FIG. 15.

A is a board twenty cms. by eight cms. on which is fixed a piece of ground glass, B, about fifteen cms. by four cms. The surface must be very finely ground—the sort called "matted" glass is best. C and D are two strips of thin sheet brass, springy, carrying each of them at one end a black lead pencil, and pivoted at the other end on a binding screw about which it can describe a circle. The ends of the binding screws must not be fixed directly in the wood, but cemented into short pieces of glass tube, which in turn are cemented into holes in the board. If this is not done the instrument will work badly in wet weather. The wood of the pencils must be cut away on one side so that the brass may come in contact with the black lead. Each pencil is then moved two or three times backwards and forwards so as to draw a circular arc upon the glass. The

current enters through one binding screw, passes into the lead pencil, and along the line drawn by it, then crosses on to the line made by the other pencil, and so out by the opposite terminal. By making the lines broader the resistance is diminished, and it is still further lessened by bringing the pencils near to each other. And by withdrawing them as far as possible apart, the resistance is increased. From time to time the glass may be cleaned with wet india-rubber, and fresh lines ruled. The range of such an instrument is from 10,000 ohms to 1,000,000 ohms.

The student may ask: Why not use a shunt to ensure the safety of the galvanometer? Because the principle of a shunt is that it provides an easy passage for almost the entire current, and so relieves the strain on the galvanometer. In this case *we do not want any current to flow* save the very small fraction which suffices to show how great the pressure or E.M.F. is. Then why not always use a graphite resistance? Because in some cases we want to measure a current *while it is flowing*. We can put a galvanometer with a shunt into a circuit, and the apparatus will still work, because the shunt allows the current to go by and relieves the galvanometer at the same time. But the graphite resistance protects it by checking the current.

Now let us suppose we desire to compare the E.M.F. of a dry cell with that of a Daniell, by means of a sensitive galvanometer. Connect one pole of the Daniell with a key, from which a wire leads to the galvanometer. Place the graphite resistance *in series* with the galvanometer, *not in parallel*, because it would then act merely as a shunt, and be absolutely useless. Connect the other side of the graphite resistance with the other pole of the battery. Now depress the key. There is a deflection, which we can make

larger or smaller by bringing the two pencils nearer together or drawing them farther apart, and so diminishing or increasing the resistance. As we have not yet provided ourselves with a standard of electro-motive force, we may as well take that of the Daniell cell, which is tolerably steady, as the unit. Accordingly, by adjusting the resistance, we bring the deflection to 100 on the scale. Next we remove the Daniell and put the dry cell in its place. This gives a deflection of 150 mms., and its E.M.F. is, therefore, 1·50 Daniells.

Then comes the question, is this E.M.F. constant while the battery is at work? To determine this important point, we connect the poles of the dry cell with a short, stout copper wire for one minute, and then, after removing the wire, test again. The deflection is now 93 mms. After short-circuiting for five minutes, we get a deflection of only 63 mms., and in 15 minutes it has fallen to 43, so that the E.M.F. is now only ·43 Daniell. But on allowing the dry cell to rest, it recovers itself. In five minutes it has risen to 85 mms., and after $3\frac{1}{2}$ hours, it is nearly 130 or 1·30 Daniell. Such a cell is therefore well suited for working a bell, which is only used at intervals, but not for electrotyping, or any purpose for which a continuous steady current is required.

How is it that a sensitive galvanometer so used will measure not current but E.M.F.?

By Ohm's law: $$\text{Current} = \frac{\text{E.M.F.}}{\text{Total resistance}}$$

With the Daniell cell we had E.M.F. = 1 Daniell (using this as the unit). Internal resistance, say 2 ohms. Resistance of galvanometer 5000 ohms. Resistance of black lead lines on glass, say 94,998 ohms. This gives

$$\text{Current} = \frac{1 \text{ Daniell}}{(2 + 5{,}000 + 94{,}998) \text{ ohms}}$$

$$= \frac{1 \text{ Daniell}}{100{,}000 \text{ ohms}} = \frac{100 \text{ divisions of the scale}}{100{,}000 \text{ ohms}}$$

Probably the resistance of the dry cell was about $\frac{1}{4}$ ohm. The other part of the circuit remaining the same, we have

$$\text{Current} = \frac{1 \text{ dry cell}}{(\frac{1}{4} + 5000 + 94{,}998) \text{ ohms}}$$

$$= \frac{150 \text{ divisions of the scale}}{99{\cdot}998\frac{1}{4} \text{ ohms}}$$

But the denominator is so very large, and so nearly equal to 100,000, that we may take it to be the same as before. In fact, it is about equal to

$$\frac{150{\cdot}003}{100{,}000}$$

and the error is only $\frac{1}{300}$ of a division—a quantity far smaller than we could detect.

Thus we see that when a battery is connected with a sensitive galvanometer in such a way that only a very small fraction of the current it is capable of supplying is allowed to pass, the deflection, which is proportional to the current actually flowing through the total resistance, is also *directly* proportional to the E.M.F. of the battery.

Standard Cells.—The next thing we require is a standard cell, so that our measurements may be expressed in volts.

The most accurate is that devised by Latimer Clark. There are several forms, of which the following is the easiest

to make. Dissolve in boiling distilled water as much zinc sulphate as it will take up, and allow the solution to cool so that the excess may crystallise out. Pour off the liquor and mix it with a quantity of perfectly pure mercurous sulphate (*not* mercuric sulphate). Boil this and let it settle, keeping the pasty sediment for use. Provide a glass tube, bent into the shape of a U, about 15 cms. high, with one leg 20 mms. in diameter and the other preferably smaller, say 5 mms.

Pour in pure mercury so as to fill the bend and rise in each limb to a height of 4 to 5 cms. Then put about 5 cms. of the pasty sediment of mercurous sulphate above mentioned into the wider limb on the top of the mercury. Provide a cork to fit this limb, and having well soaked it in melted paraffin, thrust through it a stout zinc wire, carefully cleaned and adjusted so as to dip into the paste of mercurous sulphate without touching the mercury. This forms one pole of the cell, and the other consists of a platinum wire thrust down the narrow limb of the U into the mercury.

The E.M.F. of this cell is 1·438 legal volts of 15° C.

For purposes of great accuracy its E.M.F. at any other temperature may be calculated from the formula—

$$1{\cdot}438 \left\{ 1 - 0{\cdot}00077\,(t - 15^\circ) \right\}$$

where t is the temperature of the cell in degrees Centigrade.

The cell should be made a week before it is wanted. It will keep in order for a long while if it is *never allowed to send a current.* It should only be connected with the high resistance galvanometer just long enough to read the deflection, or better still, it should be employed either in conjunction with an electrometer, or with a rheochord used after Poggendorf's method, to be presently described. It

is more expensive, but much better to make this cell on a larger scale.

Put about an inch of mercury in the bottom of a glass jar. Fix a small glass tube so as to reach well into the mercury with a platinum wire inside it for the connection. Then put in the paste of mercurous sulphate and zinc sulphate solution. Next hang up a good-sized zinc plate in the liquid, and finally seal up the cell with melted paraffin. The terminals will be as in the smaller model.

Beetz's Standard Cell.—Provide a glass U tube about 20 cms. long and 2 cms. in diameter, and fill the bend with plaster-of-Paris. When this has set thoroughly, but before it is dry, place a solution of copper sulphate in one limb, with a stout copper wire passed through a paraffined cork dipping into it, and a stout zinc wire similarly secured in the other limb, which must be nearly filled with a saturated solution of zinc sulphate. This makes in effect a Daniell's cell with plaster-of-Paris for the porous pot. The resistance is very high, and the E.M.F. is about 1·07 volt. It is cheap, and keeps in good order for a long while, but is not accurate.

The Rheochord or Potentiometer.—This, like the Wheatstone's bridge, is essentially the poor man's instrument. It affords a means not only of measuring E.M.F., but of obtaining any desired difference of potential, less than that of the battery employed, with a high degree of accuracy. In its simplest form it consists of a long wire, preferably of German silver, stretched for convenience zig-zag upon a board, the two ends being connected by stout copper wires with a battery.

Suppose the resistance of the battery is 1 ohm, and that of the wire 10 ohms, then the difference of potential

between the two ends of the wire will be $\frac{10}{11}$ths of the total E.M.F. of the circuit, and the difference of potential between the middle of the wire and either end will be half that amount, *viz.*, $\frac{5}{11}$ths of the total E.M.F.

For assuming the wire to be of the same diameter along

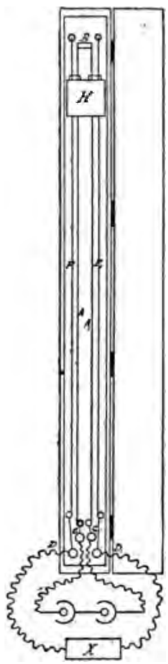


FIG. 16.

its whole length, the difference of potential will decrease regularly from one end to the other, just as the height of an inclined plane decreases in proportion as we approach the

lower end. If then we connect one terminal of a high resistance galvanometer with one end of the rheochord wire, and the other terminal with a flexible wire with which we can touch the German silver wire at any point along its length, we shall get what is called a "derived current" through the galvanometer, and the E.M.F. of this derived current—and consequently the deflection—will be proportional to the distance of the point of contact from the end with which the other terminal of the galvanometer is in connection. It must be borne in mind that this is only *absolutely* true when no current passes through the derived circuit, but it is approximately true as long as this current is small in comparison with that in the German silver wire. The following form devised by the author is described in the *Phil. Trans.*, vol. 182, A. p. 321. A, A^1, Fig. 16, is a German silver wire 4·5 metres long and of 20 ohms resistance, soldered by the middle to the brass yoke B, the resistance of which is practically zero. The two ends of the wire are attached to springs C, C^1, which keep it stretched, and through these to the terminals D, D^1.

The yokes, springs, and terminals are cemented to varnished glass pegs in the wooden trough E, which is at the same time the baseboard and the box of the instrument. Two stouter wires, F, F^1, insulated from each other and parallel to A, A^1, are attached in a similar manner to the terminals G, G^1. A heavy rider, H, carries two pairs of spring jaws, made also of German silver, which pinch the wires so as to make electrical connection between A and F, and between A^1 and F^1. Two Daniell's cells and a variable resistance are connected in series with the terminals D and D^1, and the terminals G and G^1 of the derived circuit are connected with the galvanometer or other apparatus, X.

The difference of potential in the derived circuit is directly proportional (errors of calibration excepted) to the distance of the jaws of the rider H from the yoke-piece B. The edge of the trough E is graduated in millimetres so that the position of the rider can be read off.

It remains to describe the variable resistance above referred to. This consists simply of a German silver wire stretched from one end to the other of a board and back again so as to form a long loop with parallel branches. On this rests a slider, with a piece of German silver on its under side acting as a bridge to carry the current across from one branch to the other. Terminals are attached to the ends of the wire and it is put in circuit with the battery. If the slider is close to the terminals, the current passes through it without traversing the wire, but in proportion as it is pushed away, the length of the path taken by the current is increased and the strength of it reduced in proportion.

The first step is to adjust the instrument. To begin with, the E.M.F. of the battery must be sufficient to maintain a difference of potential between the two ends of the rheochord wire greater than 2 volts. If the standard used is the Latimer Clark cell, the E.M.F. of which is 1·438 volts, the rider must be set at 1438 mms. from the yoke. Supposing the zinc of the battery to be connected with the terminal D of the main circuit and the copper to the terminal D^1, then the terminal G of the derived circuit is connected with the zinc of the standard cell, from the other pole of which a wire leads on through the graphite resistance to the sensitive galvanometer, and so round through a key to the other terminal of the derived circuit. Thus the derived circuit has in itself a standard E.M.F. which tends, directly the key

is closed, to produce a current from G to G^1, and thence by way of the main wire back to G. But the Daniells of the main circuit generate a current which, when it reaches the junction of the main wire with the derived circuit, tends to separate, part passing along the main circuit and part crossing over by the contact on the slider into the derived circuit, and, as it were, heading back the flow from the standard cell.

If therefore we can make the difference of potential between the two contacts of the slider exactly equal to that of the Latimer Clark's cell, the two will balance each other, and there will be *no deflection of the galvanometer*.

To do this, we reduce the current of the main circuit, which is purposely made too strong at first, by pushing the slider of the variable resistance away from the terminals, and so introducing a greater length of wire. As soon as the needle of the galvanometer remains at zero when the key is depressed, the adjustment is complete. The difference of potential given with the rider of the rheochord at 1438 mms. is now 1·438 volt. Therefore the difference of potential with the rider at 1000 mms. must be 1·000 volt—supposing the wire to be of even diameter—and each mm. must correspond to one thousandth of a volt. If Beetz's standard cell is used instead of Latimer Clark's, the rider must of course be set at 1070 mms.

(1) To measure the E.M.F. of any given battery, remove the standard cell, and put the one to be tested in its place, with its poles the same way. Shift the rider till the galvanometer stands at zero when the key is depressed. The distance in millimetres of the jaws of the rider from the yoke piece gives the E.M.F. in thousandths of a volt, from 0 up to 2 volts. For higher differences of potential,

either a longer wire must be used or the measurement effected indirectly or with a different instrument.

(2) To measure the current flowing in a given circuit. Insert in the circuit a resistance of 1 ohm, the two ends of which are connected with the derived circuit as in the diagram Fig. 17.

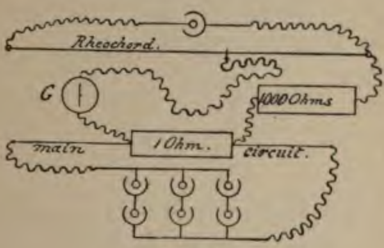


FIG. 17.

Shift the rider till the deflection of the galvanometer is zero, and the rheochord readings in millimetres will give the current in milli-amperes or thousandths of an ampere. For a very large current the resistance may be smaller—say $\frac{1}{10}$th ohm. Each division will then correspond to $\frac{1}{100}$ of an ampere. Conversely for small currents a larger resistance, *e.g.*, 10 ohms, may be taken. Before and after each measurement the rheochord should be tested with the standard cell to see if it is still correctly adjusted. A capillary electrometer will do even better than a galvanometer in this case.

The Switch.—To perform these operations quickly it is advisable to have a switch. "Pohl's Commutator," Fig. 18, is simple to make, and serves for this and many other pur-

poses. It consists usually of a block of ebonite furnished with six binding screws, each in metallic communication with a little pool of mercury. A kind of tip-bridge of stout brass

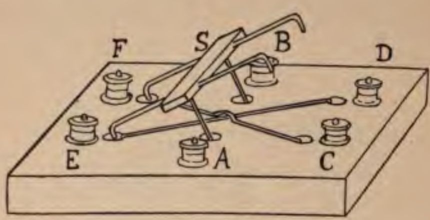


FIG. 18.

wire serves to convey the current from A to E and from B to F, when in the position represented. But if it were tilted over to the other side, the connection would be from A to C and from B to D. (Observe that S is made of glass or ebonite, so that there is no electrical communication between the two sides of the tip-bridge.) Two cross wires connect C with F, and D with E, respectively. To use it as a reversing key, join A and B to the battery, and E and F to the galvanometer, etc. To use it as a commutator for comparing batteries, etc., *take away the cross wires*, connect A and B with the rheochord, C and D with the standard cell, and E and F with the battery to be tested. Instead of ebonite, paraffin may be used. Melt enough to fill a shallow wooden box, and, when it is cold, cut out six pools for the mercury, and fix a binding screw upright in the paraffin by the side of each. Then bend down the end of each circuit wire, so as to dip into its proper pool, and fix it in position by passing it round the binding screw, which serves as a clamp. This is much better than providing a separate con-

nection, because it can be seen, and is renewed each time the apparatus is set up.

Switches and keys for use on circuits of low resistance are best made on this principle. For instance, the wires from a set of storage cells may each be brought to dip into a ½-oz. bottle, in the bottom of which is some mercury. Other similar bottles may be arranged in a circle round each of these, the wires dipping into them leading to the various galvanometers, rheochords, resistance boxes, etc., which are wanted always ready for use. Any one of these is put into circuit by means of a pair of very stout copper wires bent like a ∩, one leg of which is inserted in the centre bottle and the other in the one belonging to the circuit required. Two wires are used, so that the current may be completely cut off. For ordinary work with small currents or fairly high resistances, simple contact keys are quite good enough. But do not box them up out of sight. Arrange all contacts so that they can be cleaned. An instrument of which the details can be seen and the connections traced is more pleasing to the eye than one that only the maker can understand—the outside case is needed merely to keep the dust from those parts which have a beauty of their own to him who knows their use.

The Capillary Electrometer.—This instrument affords the simplest and cheapest means of measuring E.M.F. to anyone who has a microscope.

If a glass tube is dipped into a basin of water, the water will stand at a higher level inside the tube than it does outside, and the smaller the internal diameter the greater will be the height to which the liquid will rise. Mercury, on the other hand, which does not "wet" glass, will stand at a

lower level inside a tube dipped into it than it does outside. This phenomenon is known as "capillarity."

Soften a glass tube in the flame—draw it out in the middle and break it off. Put a drop of water into one half, and a drop of mercury in the other. The water will instantly run down into the very finest portion of the tube, but the mercury will rest at the bottom of the wide part, its surface tension resisting the pressure of its weight, and preventing it from going farther. Increase the weight by pouring in a few more drops, and it will be forced down into the narrower part, forming a little column the end of which appears to act as a spring, allowing it to descend to some point where the tube is so small that the weight cannot force it any further. Now it is found that the intensity of the surface tension varies with the electrical condition of the surface, and on this principle the capillary electrometer, invented first by Lippmann, depends. The form introduced by the author is easy to make.

Fig. 19 represents the instrument about $\frac{1}{2}$ size. A is a tube of soft soda-glass crooked at the end, and drawn out into a fine capillary tube. B is a tube bent into a V shape, with one leg longer than the other. C is a strip of thin sheet brass, about 25 mms. wide, bent round so as to clip the longer limb of B and the lower part of A just above the crook. By twisting A and B round in the clip of C, the point of A can be brought over the short limb of B, which is slid carefully up until the stouter part of the point reaches the level of the open end, and then turned slightly round so as to bring the capillary point in contact with the glass. Next, perfectly clean distilled mercury is poured into A so as nearly to fill it. The capillary must be too fine for any to flow through. Then mercury is poured into B to a

depth of 35 mms., and finally a few drops of dilute sulphuric acid of 25% are put into the short limb of B on the top of the mercury.

It remains to make the electrical connections, and to supply the pressure necessary to force the mercury into the fine part of the capillary. D is a brass tube furnished with a binding screw, and having a platinum wire soldered inside it so as to project about 12 cms. A short piece of rubber

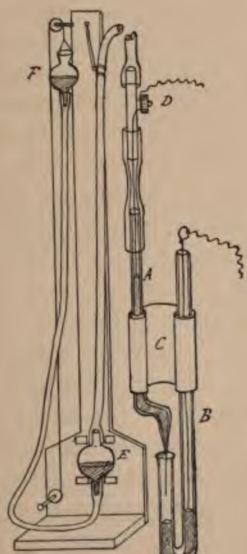


FIG. 19.

pressure tubing is secured to D, and pushed carefully over the end of A, so that the platinum wire dips into the mercury. The other end of D is attached to a pair of

pressure bulbs, E F, connected by a stout rubber tube.[1] On raising F, the mercury contained in it flows into E, compressing the air therein, the pressure of which is transmitted to the tube A, forcing the mercury down to any desired position in the capillary. F is attached to a cord by which it can be fixed at any height above E.

The circuit is completed by passing a platinum wire down the longer leg of B into the mercury on that side. A fine copper wire leads from this to a key, the other side of which is connected with the binding screw on D.

The electrometer thus prepared is secured to the stage of a microscope fixed with its tube horizontal, or nearly so—a power of 50 to 250 diameters being used. The end of the capillary is then brought into the field of view, and watched while the pressure bulb is raised. The key must be closed so as to short-circuit the terminals. At first the air which filled the tube is driven out in bubbles. *This may require a considerable pressure.* Suddenly the mercury is seen to shoot up and flow through. Then the pressure must be lowered until the mercury recedes, sucking after it the dilute sulphuric acid. Repeat this two or three times to get the end of the tube well wetted. Finally, adjust the pressure so that the top of the mercury column occupies about the middle of the field of view. Now open the key.

(1) Touch one terminal with the forefinger, and the other with the thumb. The mercury rises or falls according as the pressure or friction is greater on one or the other.

(2) Connect the terminals with the derived circuit of the rheochord. The movement of the mercury is *in the same*

[1] This part of the apparatus is drawn on a smaller scale—it should be about 80 cms. high.

direction as the current, and in a good instrument it is proportional to the difference of potential introduced.

Up to about ·5 volt the alteration of pressure required to *bring the mercury back to any given zero-point is proportional to the difference of potential causing it to move away from that position.*

After a while crystals of mercury sulphate sometimes form in the capillary. These may be got rid of by electrolysing them with a current of about ·5 volt directed from B towards A. The acid must then be washed out and replaced by fresh. No current passes through an electrometer except when the mercury is moving, and then only a certain definite quantity depending on the dimensions of the instrument.

The author's experiments have shown that the capillary electrometer may be regarded as a condenser of fixed capacity. In some instruments it is as low as ·1 microfarad, and in others as much as 30· microfarads. An average capacity is about ·3 M.F. A good capillary will respond to a difference of potential of $\frac{1}{30000}$ volt. Unlike the galvanometer, the sensitiveness of this instrument is *not affected by resistance.* The scale readings are the same with a megohm in circuit as without it, only *the mercury moves more slowly.* The point wherein it differs from all other electrical instruments is in the rapidity of its action. Under normal circumstances it is absolutely dead-beat, and in a good instrument the first half of an excursion takes less than $\frac{1}{100}$th second, and the movement is practically completed in $\frac{1}{10}$th of a second.[1] The capillary electrometer

[1] See "On the Time-Relations of the Excursions of the Capillary Electrometer," by G. J. Burch. *Philosophical Transactions*, vol. 183 A, p. 81.

may be used for all experiments with a resistance box or rheochord, instead of a high resistance galvanometer.

(3) Wrap a pad of flannel moistened with salt and water round the end of a copper wire connected with one terminal of the instrument, and press it against the skin over the apex of the heart. Take the bare end of the other wire in the mouth. At every beat of the heart the column of mercury will be seen to dance up and down, owing to the electrical changes which accompany the contraction of the heart muscles. This experiment is due to Dr. A. Waller. It is useful as a test of the excellence of the electrometer, as none but a fairly good one will show it.

Absolute cleanliness and purity of the materials is the secret of success in making these instruments. The glass used must be cleaned with aqua regia, followed by distilled water, before the capillary is drawn. The capillary should not be too fine—one that requires a working pressure of from 15 to 30 cms. of mercury is best for most purposes. When not in use, the pressure bulb should be lowered and the instrument short-circuited.

The Quadrant Electrometer.—This instrument was invented by Sir William Thomson. In its complete form it is too complicated to describe here, but the principle on which it is based is simple enough.

A light aluminium "needle," shaped like two tennis racquets joined together by the handles (Fig 20. the dotted line), hangs by a silk fibre inside a flat brass box cut into four quarters called quadrants, which we may distinguish as north, south, east, and west. They are supported on glass pillars so as not to touch one another, and the N quadrant is connected with the S, and the E with the W.

Referring to Chapter I. it will be remembered that like charges repel and unlike charges attract each other. Let us suppose we connect the N and S quadrants with the + or positive pole of a battery, and the E and W quadrants with the — or negative pole, and that the needle is at rest under the line of separation between them from N E to S W.

If we can give the needle a + charge, one end will be re-

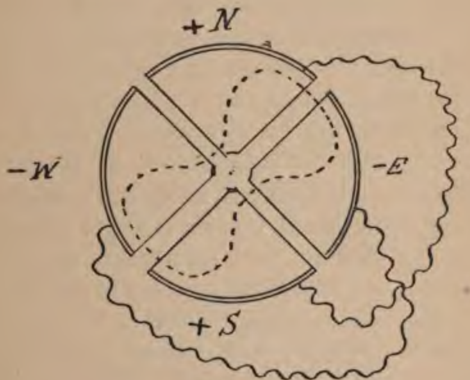


FIG. 20.

pelled by the N and attracted by the E quadrant, and the other end will be repelled from S and attracted towards W, so that it will be deflected clockwise.

We have therefore to provide three things, *viz.*, a means of charging the needle, something to resist the deflection and send it back to zero, and something to measure the deflection. This last is managed exactly as in the reflecting galvanometer. A small mirror, M, Fig. 21, attached to the stem on which the needle hangs, serves to throw a spot of

light on a tangent scale. The necessary resistance to deflection is given either by attaching a small magnet to the stem of the needle, or by hanging it from two silk fibres, S S, side by side instead of one. This is called the method of "*bifilar suspension*," and it has some advantages. The charge is communicated to the needle by connecting it with a Leyden jar in the following manner.

On the stand of the instrument, under the quadrants, is placed a beaker or a small wide-mouthed bottle, J, coated on the outside and the bottom with tinfoil and about half full of strong sulphuric acid, which forms the inside coating and also, from its powerful affinity for water, keeps the air dry inside the apparatus. The lower part of the stem of the needle is made of a platinum wire, P, and dips into the acid, which has no action on it. A bent wire, W, with a brass knob at each end, is brought through the case in such a position that by twisting it round it can be made to touch the platinum, and so transmit sparks from an electrophorous or a Wimshurst machine to the inside of the jar, while the outside is put to earth. When a sufficient charge has been thus imparted, the wire is pushed away and the needle allowed to swing free. Then the controlling magnet, or, if the bifilar suspension is used, the cap C, to which the silk filaments are attached, is twisted round till the needle hangs exactly under the line of separation between the quadrants, and the lamp and screen adjusted. On communicating a very small difference of potential to the quadrants, the needle will be attracted by one pair and repelled by the other, and the deflections, as measured by the movement of the spot of light, will, if they are not large, be proportional to the E.M.F. The stronger the charge of the jar, the more sensitive the instrument becomes, and as

no current passes, it serves to measure E.M.F. directly. For instance, charge the jar with a succession of sparks from the electrophorus until the Latimer Clark standard cell gives a deflection of about 143·8 mms. Then bring the scale a little nearer or move it further off until the reading is exactly 143·8 mms. (this being easier than altering the charge), and now each millimetre will correspond to the hundredth of a volt. If the insulation is good, the charge should last a long while. As with the capillary electrometer, the touch of a finger on the terminals will suffice to cause a deflection.

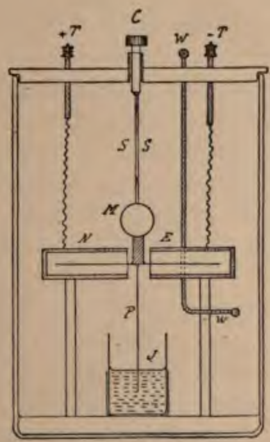


FIG. 21.

Fig. 21 shows the general arrangement of the instrument in section. It should be covered with a glass shade, *outside which is a cage* (not shown) *of wire netting*, other-

wise the presence of a charged body in the room, even at several yards distance, will affect the needle.

A gap may be left in the netting to allow the light to pass to and from the mirror.

The quadrants are supported on varnished glass pillars, which may be set in paraffin at the base. The terminals, + T and — T, are connected to the quadrants as indicated in Figs. 20 and 21.

CHAPTER IX.

ELECTROLYSIS.

WE have already seen that when two metals are immersed in a liquid capable of acting chemically upon one of them, and the two are connected by another conductor, an electric current circulates, from the metal which is being dissolved, through the liquid to the other metal, and back again by the conductor. The intensity of this current depends on the nature of the two metals and of the liquid, and its quantity bears a definite proportion to the weight of the particular metal dissolved. Thus the formation of a chemical compound is accompanied by the generation of a current.

Conversely: if a current is made to pass through a chemical compound in solution, it is decomposed in quantities bearing a definite proportion—different for each element—to the amount of current transmitted, the minimum electro-motive force necessary to effect the decomposition depending on the nature of the compound and of the new substances into which it is separated.

This process of chemical decomposition by the passage of a current was called by Faraday *electrolysis*. All liquids are not capable of being so treated. Some, as turpentine

and petroleum, will not convey a current, but act as insulators. Others, as mercury and molten metals, which conduct well, are simply heated by the passage of the current, but others, as the compounds of the metals, and such bodies as are soluble in water, are not only heated, but also decomposed. Such substances are termed "electrolytes."

In 1800, Nicholson and Carlisle discovered that when a current is passed through water, the liquid is decomposed, bubbles of gas being given off from the wires immersed in it.

Perfectly pure water is almost a non-conductor, but if mixed with a small quantity of sulphuric acid, its resistance is greatly reduced, and it is easily decomposed.

(1) Couple together three or more Daniells in series, and let the two wires dip into a small beaker containing dilute sulphuric acid. The end of the wire which comes from the copper or positive pole of the battery is blackened. This end is called the *anode*—it is that by which the current arrives according to our convention as regards its direction. The end of the other wire, by which the current leaves the beaker to go to the zinc of the battery, is called the *kathode*. It becomes covered with bubbles, which rise to the surface, and may be collected in an inverted test tube filled with the liquid and supported with its mouth beneath the surface of it. These bubbles consist of hydrogen. As soon as the tube is quite full it may by lifted up and a light applied, when the gas will catch fire. Repeat the experiment, using platinum wires to dip into the acid instead of copper. Now bubbles will be given off from both wires. If they are simultaneously collected in two separate tubes, it will be found that only half as much gas is produced by the anode as by the kathode. It is not inflammable, but if the red-

hot end of a wooden match just blown out is inserted in the tube containing it, the spark will glow brightly, and the match will burst into flame if there is sufficient gas in the tube. This property indicates that the substance given off at the anode is oxygen.

The current has decomposed some of the water into its elements, and as each molecule of water consists of two atoms of hydrogen united to one atom of oxygen, the volume of hydrogen set free is twice as great as that of the oxygen.

The reason why oxygen was not given off when copper wires were used is that it unites easily with copper, as was shown by the blackening of the wire.

If the student cannot obtain platinum he may employ a stick of black lead, twisting the copper wire round one end of it, and dipping the other end in the liquid. But care must be taken not to wet the part where the copper touches the black lead.

(2) Electrolyse in the same way a dilute solution of hydrochloric acid, or hydrogen chloride.

Hydrogen is given off from the kathode as before, but a yellowish gas, which will be recognised by its odour as chlorine, will appear at the anode, showing that the current has separated the hydrogen from the chlorine.

(3) Electrolyse a solution of common salt, or sodium chloride. The same smell of chlorine will be noticed at the anode, and caustic soda, resulting from the combination of sodium with some of the water, will appear at the kathode. In order to demonstrate this we must use an "indicator." Grind up the petals of two or three violas or dahlias—or any red or purple flower—with a little salt and water, and moisten a piece of white blotting paper laid on a plate with

the coloured liquid. Then let the two poles of the battery rest on the wet paper. Round the kathode it will turn blue, or green if violas were used, while round the anode it will be bleached by the chlorine given off.

Vary the experiment by grinding up some coloured petals with soda sulphate instead of sodium chloride. This will be separated into soda at the kathode, where a blue colouration will appear, and sulphuric acid at the anode, which will turn the juice of the petals red without bleaching it.

The hue of nearly all these vegetable colouring matters is changed to red by the action of an acid; and to purple, blue, or green, according to the particular kind of flower it is obtained from, by an alkali: but when an acid and an alkali are mixed together in exactly the proportion in which they naturally combine, the resulting compound, termed a neutral salt, has no action upon the colour. Hence these vegetable dyes are used as "indicators" to show the presence of free acid or free alkali.

(4) Bend a piece of glass tube into the shape of a V, and half fill it with soda sulphate solution coloured with litmus or the petals of some flower. Dip the two *electrodes* or wires from the battery, one in each branch. The liquid surrounding the anode will become red, and that near the kathode blue. Take out the wires, stop the ends of the V tube with the two thumbs, and shake the liquid so as to mix it well. It will all be restored to its original colour, showing that the current did not destroy the salt, but simply separated it into acid and alkali, so that when these were allowed to recombine, the salt was reformed as before.

(5) The next step is to find out how much of any given compound can be thus separated or electrolysed by a certain quantity of current. To do this we must collect the pro-

ducts of decomposition and measure them. This in the case of water entails certain precautions owing to the fact that the oxygen and hydrogen evolved, being gases, are elastic. If the inverted tubes in which they are contained are dipped deep in the water, the gas is compressed into a smaller volume, and if they are raised up it expands.

Graduated measuring glasses may be used as collecting vessels, but before reading off the quantity obtained, they must be raised or lowered in the vessel till the liquid inside the tube stands at the same level as it does outside. Then the contained gas is under atmospheric pressure. But this again varies with the height of the barometer. It is usual to take 760 mms. or 30 inches as the standard pressure. If therefore the barometer stands at 31 inches, we must multiply the quantity of gas measured by $\frac{31}{30}$ and so on, to get the volume at standard pressure.

Once more, gases expand with heat, and contract with cold, at the rate of $\frac{1}{273}$ part of their volume for every degree Centigrade. To correct for temperature, we must multiply by $\frac{273}{273 + t^\circ}$ where t° is the temperature in degrees Centigrade at the time.

It has been already shown that in the electrolysis of water the bulk of hydrogen is twice that of the oxygen evolved. It is better to collect the gases separately, partly because the mixture is explosive, and partly because platinum has the property of causing them slowly to recombine, and oxygen dissolves to some extent in the liquid. It is sufficient to collect the hydrogen alone, and it is found that a current of 1 ampere will liberate in 1 second 0·1157 cubic centimetres of hydrogen, measured under a pressure of 760 mms. of mercury at 0° Centigrade.

A *voltameter* is an apparatus for measuring electrical currents, by determining accurately the quantity of hydrogen evolved in a given time. Fig. 22 illustrates diagrammatically a form which can be made by the student.

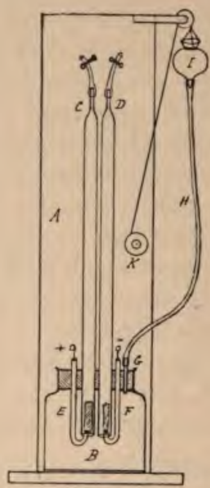


FIG. 22

A is a board fixed upright on a wooden base. B is a wide-mouthed bottle fitted with a cork well soaked in melted paraffin. C and D are glass tubes about one cm. by thirty cms. They are drawn shorter to save space. They pass through the cork about halfway down the bottle, and are drawn off smaller at the top, and fitted with short pieces of rubber-tubing closed by pinch-cocks. American letter-clips will do. E and F are glass tubes to insulate the electrodes, each of which is made of a strip of platinum foil two or three cms. long, and wide enough just to enter the

tube C or D. This is attached to a platinum wire, either by welding (not soldering), or by pricking four holes in a line, and threading the wire backwards and forwards through them and fixing it with a tap of a hammer. The wire is then passed through the tube E, which is afterwards completely filled up with melted paraffin, and fixed in place in the cork so that no part of the electrode save that in the tube C is exposed to the acid. F is fitted up in the same way. G is a short glass tube which comes just level with the cork inside, and outside is fitted with a caoutchouc tube H, connected with the glass bulb I. A cord passing over the brass pulley J to a bobbin K, serves to raise and lower the bulb I, or fix it in any position. When all is completed, seal the cork in B by covering it all over with melted paraffin.

To fill the instrument, open the clamps on C and D, raise I till the middle of it is on a level with the top of them, and pour dilute sulphuric acid into the bulb I till it comes just above the clamps. Then tighten them, and lower the bulb. B and C and D will now be full of acid. Connect the ends of the platinum wires E and F with the battery circuit, and close the key. Hydrogen will collect in C, and oxygen in D, or *vice versâ* according to the direction of the current. To measure the gas, open the key, and raise or lower the bulb I till the liquid in it is on a level with that in the tube containing hydrogen. It is then under atmospheric pressure, and needs only to have its volume read off—for which purpose the tube should be graduated in cubic centimetres—and to be corrected for temperature and pressure. Then open the clamp, and hold a lighted match over it with one hand, while with the other you raise the bulb I. This will force the hydrogen out of the tube, and it will catch

fire. Close the clamp again, and measure the oxygen by adjusting the bulb till the liquid in it is on a level with that in the oxygen tube. The quantity should be half that of the hydrogen. Then loosen the clamp, and hold a glowing splinter of wood over the end of the tube. When the gas is expelled by raising the bulb, it will cause the spark to glow brightly, and the wood will burst into flame. Care must be taken not to spill the acid.

Should any get on the clothes, it must instantly be neutralised with soda or ammonia, or failing these, with chalk, which can easily be washed out, whereas the acid would destroy both the colour and the fabric.

To graduate the tubes C and D, turn them upside down with the clamps closed, and drop in with a pipette measured quantities of water, 1 cc. at a time, marking the height of the liquid with a file dipped in turpentine, in which some camphor has been dissolved. This should be done before they are fixed in the cork.

(6) *The copper voltameter.*

Take two pieces of sheet copper about three cms. by five cms., and after weighing, immerse them to a depth of three cms. in a solution of pure copper sulphate. The plates should hang about one and a half cms. apart. Connect them with a battery and let there be a tangent galvanometer in the same circuit. All the while the current passes through the liquid the needle is deflected. After a definite interval, remove the plates, rinse them in water, dry, and weigh. The anode is found to have lost weight, and the kathode to have gained approximately an equal amount. Here no decomposition, in the strict sense, was possible. The copper sulphate, $CuSO_4$, was resolved into copper at the kathode and "sulphate" at the anode—if we may be

allowed to use that term for SO_4, the residue of the molecule—and the latter, finding itself in contact with a mass of the same element that it had been forced to drop at the other end of the circuit, took up a corresponding number of atoms from it, reducing the weight of the anode. On the other hand, the copper set free at the kathode adhered to it, making it heavier by the same amount. Instead therefore of a decomposition, there has been a *transference of copper from one pole to the other.* If the anode had been a sheet of platinum, then the SO_4, unable to attack it, would have been forced to decompose some of the water in the vicinity, thus

$$H_2O + SO_4 = H_2SO_4 + O$$

forming hydrogen sulphate (sulphuric acid) and setting free oxygen. This would have required a greater intensity of current.

A current of 1 ampere will deposit 0·00032959 gramme of copper per second.

How long therefore should the experiment last to produce an appreciable change of weight in the electrodes? We must count up the E.M.F. and the resistance in circuit.

Suppose the battery to consist of one Daniell cell of E.M.F. = 1·07 volts and resistance 2 ohms. That of the tangent galvanometer is, say 1 ohm. The copper plates of the voltameter are 3 cms. broad, immersed to a depth of 3 cms., giving 9 square cms. of surface. The resistance of a column of a saturated solution of copper sulphate 1 cm. broad and 1 cm. deep is 29·3 ohms for each centimetre of its length.[1] This is called its specific resistance. The length in this case is 1½ cms., so the resistance is 43·95

[1] Ewing and MacGregor, *Transactions of the Royal Society of Edinburgh*, vol. xxvii.

ohms for 1 square cm. But as the area of the plates is 9 square cms., the total resistance is one-ninth of this, *viz.*, 4·88 ohms.

This gives the total current—

$$\frac{1·07}{2+1+4·88}=\frac{1·07}{7·88}=0·136 \text{ ohm nearly.}$$

This would deposit about 0·0000448 gm. of copper per second. We may, therefore, expect to get half a gramme in 3 hours.

Suppose 3 cells were used in series, the current would then be

$$\frac{1·07+1·07+1·07}{2+2+2+1+4·88}=\frac{3·21}{11·88}=·27 \text{ ampere.}$$

The student may calculate how best to arrange a number of Daniells for this purpose. But he must allow at least 6·25 square centimetres of electrode to each ampere of current or the deposit will not stick to the plates. With those described, the current must not much exceed 1·4 ampere. Other metals may be deposited in the same way—zinc, for instance, using two plates of zinc in a solution of zinc sulphate.

This power of an electric current to separate chemical compounds is made use of in many ways.

First, we may take the simple fact of the separation. It affords a means of reducing metals from their ores. For instance, one process by which aluminium is manufactured consists in melting aluminium fluoride in a cast-iron pot lined with carbon, which forms the negative electrode, the positive being a rod of carbon dipping into the fused mass.

The aluminium collects on the surface of the carbon, and, falling to the bottom, is removed by a tap-hole. The current is supplied by a dynamo, and the energy expended

per kilogramme of aluminium produced is 31·3 H.P.-hour. The difference of potential at the electrodes is 4·55 volts, and they are of such dimensions that the density of the current is $\frac{3}{4}$ ampere at the positive pole, and $\frac{1}{20}$ ampere at the negative pole per square centimetre of surface.

Copper is also reduced from its ores by electrolysis, and sodium, potassium, and magnesium have been largely manufactured in this way. But the most familiar applications of the process are known as electrotyping and electroplating. Here advantage is taken of the fact that if the current is not too dense—that is, if the area of the electrode is not too great in proportion to the flow—the deposit is hard and firm and adheres tightly to its surface. In electrotyping the object is to produce a film of copper which shall be an exact copy of the electrode, and which can be separated from it. For this purpose a mould is taken in wax or guttapercha of the thing to be copied—a coin, for instance—and in order to give it a conducting surface it is brushed carefully over with very finely powdered black lead. A copper wire having been twisted about it so as to come into contact with the black lead at a good many points, it is hung in a solution of copper sulphate, in place of the kathode, the anode being a plate of copper placed near it in the liquid. In a short time the black lead is seen to become covered with a deposit of metallic copper, which gradually increases until it is of sufficient thickness to bear being detached. Soft metal, such as solder, may then be cast into the back of this film, the face of which is an exact copy of the original coin. Many of the illustrations in books are printed from copies of the engraved wood-blocks prepared in this way, as they do not wear out so quickly as the originals. In electroplating, on the other

hand, advantage is taken of the fact that the metal adheres tightly to the surface on which it is deposited. For this reason the objects are first made absolutely clean, all tarnish as well as grease being removed by chemical means, and they are then hung up in the bath in which electrolysis is to take place. For gilding, the bath may be composed of 1 part gold chloride, 10 parts potassium cyanide, and 200 parts water, the anode being a plate of gold. As fast as gold is deposited from the solution on the kathode, more is dissolved from the anode, and by weighing this before and after the operation the quantity of metal put on can be ascertained.

For silvering, the bath may be made of 2 parts silver cyanide, with 2 parts potassium cyanide, in 250 parts of water, the anode being, of course, a plate of silver, which may be weighed, and the amount of the deposit measured as before.

Of late years, nickel has come into general use as a coating for articles made of iron or brass to preserve them from rust. This also is applied by electrolysis.

Yet another property of these deposits is of the greatest value. The student cannot fail to observe that whereas copper is naturally soft, that prepared by electrolysis is extremely stiff in proportion to its thickness. Iron deposited in this way has almost the hardness of steel.

Accordingly, engraved copper-plates, before being used for printing, are immersed as kathodes in a bath of ammonium chloride containing iron in solution, with a large sheet of iron as the anode. In half-an-hour the whole surface of the copper is covered with a bright coating of iron, so thin as not to destroy the delicacy of the finest por-

tions of the engraving, but so hard that thousands instead of hundreds of impressions may be taken from it. And when it shows signs of wear, this film of iron may be dissolved off by acids without touching the copper, and replaced by a new one.

Hitherto we have considered only the fact that metals can be so deposited. Our knowledge of the *quantity* deposited by a given current may be put to practical use. It affords a ready means of measuring currents without needing to know what resistance is in circuit, or what is the law of our galvanometer. For although in a perfectly adjusted tangent galvanometer the deflection may be directly proportional to the current for some distance along the scale, we must not assume that every home-made instrument follows this law exactly.

By electrolysis, using a voltameter, the student may "calibrate" his galvanometer, *i.e.*, he may find out exactly the value for every tenth division of the scale in terms of a known current. And not only will he then know whether a certain deflection indicates exactly twice as much current as one of half that value, but exactly how many divisions of his scale go to 1 ampere; that is to say, he will have ascertained the *absolute value* of the scale-readings of his instrument.

Now, in work of this sort, with limited apparatus, it is often possible to arrange the experiments so as to avoid trouble and calculations. Suppose we possess a graduated measuring glass holding 25 cc.—the taller it is the better—in fact, a burette will do very well. We collect only the hydrogen, so we place the kathode under the mouth of the tube, and fix the anode somewhere outside, allowing the oxygen to escape into the air, remembering that the dis-

tance between kathode and anode must not be altered *during an experiment*, otherwise the resistance, and consequently the current, would be changed.

Now a current of 1 ampere would evolve 0·1157 cc. of hydrogen per second, with the barometer at 760 mms. and the thermometer at 0° C.

By proportion, we find that it would take 8·643 seconds to evolve 10 cc. of the gas, so that, roughly, we may say that with 1 ampere we should get 20 cc. in 17·3 seconds. If, therefore, it requires 34·6 seconds to fill the measure to that mark, we know that the current was half an ampere. But probably the barometer was not 760, nor the thermometer at freezing point. Moreover, the gas contains a certain proportion, varying with the temperature, of aqueous vapour derived from the liquid in the voltameter. If acid of 10 per cent. is used, the following correction must be made:

At 13° C.	deduct	10	mms.	From the height of the barometer.
14° C.	„	$10\frac{3}{4}$	„	
15° C.	„	$11\frac{1}{2}$	„	
16° C.	„	$12\frac{1}{4}$	„	
17° C.	„	13	„	

For example, suppose the barometer stands at 753 mms. and the temperature is 17° C.,

$$753 - 13 = 740, \text{ the pressure of the dry gas.}$$

Then the true volume is

$$V' = V \cdot \frac{740}{760} \cdot \frac{273}{273+17} = V \cdot \frac{20202}{22040}$$

i.e., about $\frac{10}{11}$ of 20 cc. Therefore to collect 20 cc. of *dry* gas, with a current of 1 ampere, under these conditions we must allow $\frac{11}{10}$ of 17·3 seconds, or 19.03 seconds. In measuring, the tube must be raised or lowered until the

liquid inside is exactly on a level with that in the vessel, otherwise a further correction will be needed.

Having prepared the voltameter, close the key at a given instant, and let the current pass until you have 20 cc. of gas. Switch it off, and note how many seconds have elapsed. Then—

Duration of experiment : 19·03 seconds :: 1 ampere : current measured.

During this time the deflection of the galvanometer should have been constant. It also must be noted and entered upon a table, with the value of the current in decimals of an ampere against it. We now require to change the current and find a new value with the corresponding galvanometer reading. Either we may put in more cells to increase, or more resistance to diminish it. Or we may shift the anode to a greater distance from the kathode, and so reduce the current.

After a number of such experiments, we can make a list of deflections on the tangent scale, with the corresponding currents in amperes. If we find that in each case the current bears the same proportion to the scale reading, the galvanometer obeys the tangent law. If not, we must draw up a table of deflections, with the approximate value of each in amperes.

With care the results will be as nearly correct as can be expected with such simple apparatus.

It may be asked, what would happen if several voltameters were joined up together like the cells in a battery?

First suppose them connected in parallel. Each would take a different fraction of the current according to its resistance, but the sum total of the gas evolved in the whole

of them would equal that given off by the same current passing through a single voltameter. If they were joined in series, then as the whole current must pass through each, each would evolve the same quantity of gas. But as a number of cells in series *gives* a higher electro-motive force than one, so a number of voltameters in series *requires* a higher electro-motive force to drive the same amount of current through it.

But suppose those voltameters were all *of different kinds?* Suppose one to be an ordinary sulphuric acid voltameter, and another copper in copper sulphate, and the next zinc in zinc sulphate, and the next silver in silver nitrate all joined in series and a current sent through, what would happen? We should have the most interesting proof possible of the relation between chemical action and electric currents, and of the validity of the atomic theory. The quantity of gas given off or metal deposited would be different in each case, but it would be *proportional to the chemical equivalents of the various elements.*

If we could weigh the hydrogen—and we can calculate the weight if we know the volume of it—we should find that for every gramme of hydrogen given off there would be deposited in the copper voltameter 31·5 gms. of copper, and in the silver cell 108 gms. of silver, while from the zinc anode there would be taken away 32·5 gms. of zinc, which would be found duly deposited on the zinc kathode at the other side of the bath of zinc sulphate. Atom for atom through the whole chain of cells, precisely the same changes are effected. Each silver atom weighs 108 times as much as a hydrogen atom, so the weight of silver deposited is 108 times as great, *but it consists of the same number of atoms.*

A copper atom is 63 times the weight of a hydrogen atom, but then it is divalent in copper sulphate, whereas hydrogen is only monovalent.

A monovalent atom is like a man with one hand—it can only hold and be held by one thing at a time. Copper, being divalent, can hold two things, or if necessary occupy the entire holding power of an atom which like itself is divalent, just as two men can grasp each other by both hands. Therefore the current which could unloose two atoms of hydrogen or of silver, can only separate one copper atom from the two bonds that hold it. So there is only 31·5 grammes of copper deposited to the gramme of hydrogen. Similarly with zinc, the atomic weight of which is 65; but because it is divalent, only 32·5 times the weight of the hydrogen is transferred. But there are other salts called cuprous salts, in which copper acts as though it were monovalent, and if these are electrolysed, the full equivalent of 63 times the weight of hydrogen is separated from them. Thus electrolysis confirms the theories of chemistry.

What has been said may be summed up in the following laws of electrolysis quoted from Silvanus Thompson's "Elementary Lessons on Electricity and Magnetism."

"(i.) The amount of chemical action is equal at all points of a circuit. (Illustrated by the voltameters in series.)

"(ii.) The amount of an ion liberated at an electrode in a given time is proportional to the strength of the current.

"(iii.) The amount of an ion liberated at an electrode in one second is equal to the strength of the current multiplied by the 'electro-chemical equivalent' of the ion."

Also, "The weight (in grammes) of an element deposited by electrolysis is found by multiplying its electro-chemical equivalent by the strength of the current (in amperes) by

the time (in seconds) during which the current continues to flow."

The name of "*ion*" was given by Faraday to the atoms separated by the action of the current from any compound, those going to the anode being called "*anions*," and those gathering at the kathode "*kathions*." Oxygen chlorine and acid radicles are anions, and go to that part of the cell where the current enters, while hydrogen and the metals and bases are kathions, and are found at the kathode where the current leaves the cell. Anions are sometimes spoken of as "electro-negative," and kathions as "electro-positive."

The chemical equivalent of hydrogen is unity, and its electro-chemical equivalent, or the weight evolved in one second by a current of 1 ampere, is given by Lord Rayleigh as ·000010352 gm., by Mascart as ·000010415 gm., and by Kohlrausch as ·000010354 gm. The electro-chemical equivalent of any other element is found by multiplying its chemical equivalent by the electro-chemical equivalent of hydrogen, and it represents the weight in grammes of the element in question which would be deposited in one second by a current of 1 ampere.

The chemical equivalent of a metal is its atomic weight divided by its valency. (See Table I. Appendix.)

Storage Cells.—It will probably occur to the student that after a battery has been exhausted by the consumption of all its acid it might be possible to restore it by sending a current through it the reverse way, and so separating the zinc from the acid, and re-depositing it on the remains of the zinc plate. There are practical reasons why this proceeding would not be of much use, except in certain specially constructed cells, but the

possibility of such a proceeding may be easily demonstrated. Arrange a voltameter for the decomposition of water, collecting the oxygen and hydrogen in separate tubes. When sufficient has been obtained, push up the electrode in each so that half of it may project above the liquid into the gas. Remove the battery and join the ends of the two wires. The needle of the galvanometer will be deflected in the opposite direction, and the gases which were separated by the superior power of the battery current will now give out a return current of their own, combining in the act, *although they are in separate tubes.* This is Sir W. Grove's gas battery, and four such cells in series will decompose water.

In 1860 Gaston Planté made an experiment on similar lines, which has led to results of great importance. He placed two sheets of lead in a solution of sulphuric acid, and sent a current through from one to the other. Lead sulphate being practically insoluble in dilute sulphuric acid —one part requiring 36,504 parts of the liquid to dissolve it—the metal cannot be transferred from anode to kathode as in the case of copper. The energy of the current is therefore expended, in the first place, on the water which it decomposes evolving hydrogen at the kathode, as in a voltameter with platinum electrodes. But the oxygen at the anode acts upon the metal there, forming a brown film of lead dioxide on it. This, when the battery is taken away, furnishes a powerful return current, giving up part of its oxygen, which acts on the metallic surface of the kathode. Planté found further, that if next time the cell was electrolysed it was reversed so as to oxidise the surface of what was previously the kathode, the metal was acted on to a greater depth, so that the return current would last longer

than before; and by a series of reversals he succeeded in making a cell which would thus by the chemical effect of electrolysis, store up, as it were, a considerable amount of current. Faure, in 1881 rendered the cell practically available by coating the two plates with red lead, which is a compound of lead with oxygen, thus furnishing a material which could be readily changed by the action of the current, on the one hand, at the kathode, into metallic lead in spongy crystals offering a large surface to the acid, and, on the other hand, at the anode, into a porous coating of the brown dioxide. Accordingly on passing a current through a cell composed of two lead plates coated with red lead, and placed in dilute sulphuric acid, one—the kathode—is seen to become grey, while the other—the anode—turns brown.

Such a cell, after being charged in opposite directions several times, affords a current of great constancy and quantity, having an E.M.F. of about 2·2 volts. These secondary batteries or storage cells will remain charged for a long time. They should always be recharged before the current they give has diminished much, by sending through them a current in the opposite direction until gas begins to be evolved from the kathode. They improve by use until the plates become disintegrated.

But if we had no other means of generating electricity than those hitherto described, these cells would be of little use. There is always a certain loss in storage, and it is only because we can produce electrical currents cheaply by means of dynamos that the storage cell has become important to the electrical engineer.

The uses to which it is put will be described in the chapter on Electric Lighting.

CHAPTER X.

INDUCTION.

ALMOST without exception the practical applications of electricity depend on the relation of one branch of the science to another. Thus in telegraphy we employ a current to produce magnetic effects which serve to transmit signals, and by their means, ideas. In electric lighting and electric welding we take advantage of the fact that the maintenance of a current implies the evolution of heat. As has been shown in the last chapter, we avail ourselves of the relation between chemical change and electrical energy for coating one metal with another as well as for generating a current. In fact the mariner's compass affords almost the only instance of the use of one form of electrical energy apart from any other; for the lightning conductor, which is solely intended to dissipate superfluous charges, can hardly be said to "use" them.

Singularly enough, the most important developments of the science have grown out of those properties of the current which were regarded by their discoverers as least likely, on account of the feeble nature of the effects as they observed them, to lead to any practical results. We proceed, therefore, to study the influence of currents upon

magnets, and of currents upon currents, and also of a current in one wire upon other wires near it.

When Oersted discovered that a magnetised needle tends to place itself at right angles to a wire through which a current is flowing, the subject was taken up by other scientists. Many attempts had been made to discover the relation between magnetism and electricity, but with no definite result. They had tried to magnetise needles, for instance, by passing strong shocks through from end to end, but now the key to the mystery was obtained—the magnetic force sets at right angles to the current force.

On Monday the 11th of September, 1820, the news of Oersted's discovery reached Paris, and his experiments were repeated before the members of the Academy. At the next meeting on Sept. 18, Ampère extended the discovery still farther. If a current acts upon a magnet, one current must act upon another. He showed that two currents in the same direction attract, and in opposite directions, repel each other. Then Arago found that iron filings are attracted by the wire of a battery when the circuit is closed, and fall off when it is broken. Five years later a bar of steel was made into a powerful magnet by winding a copper wire round it and sending a current through; but it was not until 1837 that the idea came to Sturgeon to try the same experiment with a bar of soft iron. He found that the lifting power it developed was enormously greater than in the case of steel, but with this difference: the moment the battery current ceased to flow, the magnetism of the iron vanished, whereas with steel a good proportion of it was permanent. This discovery was one of the most important of the series, for it is on this property which soft iron possesses of *losing* as well as acquiring magnetism rapidly that most of our electrical

appliances depend. The laws of the action of current upon current and the relation between currents and magnets may best be studied by making a few simple experiments.

(1) Coil a copper wire—No. 20—round a pencil, so as to make a spiral of 30 or 40 turns, about 15 cms. long, bringing the two ends back in a straight line in the middle. Take a strip of sheet copper about two cms. by five cms., and a similar one of zinc, and fix them side by side, like the plates of a battery, in a large flat cork or bung big enough to float them. Twist the two ends of the wire spiral round the parts of the plates which come above the cork so as to connect them, and float the whole in a basin of dilute sulphuric acid. A little care in the construction will be necessary to make it float upright; and to keep it from getting up against the sides of the vessel, a fine silk fibre may be attached to the middle ring of the spiral so as to take a small fraction off the weight. A current of electricity will circulate through the spiral, which will behave exactly as a magnet, setting itself north and south, and being attracted and repelled by other magnets in the same way as the needle of a compass.

(2) Examine in which direction the current flows (according to the usual convention), and it will be found that if the observer imagines himself to swim with the current, keeping his face towards the axis of the spiral, *the end of it on his left hand will* be the north-seeking pole. This is called Ampère's rule.

(3) Place a watch face upwards on the table. Imagine a current to travel round it in the same direction as the minute hand. Then, applying Ampère's rule, it will be apparent that the end of the axle which is uppermost will represent the south-seeking pole of the magnet, for it would

be on the right hand of a man swimming with the current.

(4) Place a second watch by the side of the first. Obviously this will represent a second magnet, also with its south-seeking pole upwards, and therefore in a position to be repelled by the first. But as the minute hand of one passes from II. to IV., it will point in succession to the X., IX., and VIII. of the other, *i.e.*, in the *opposite direction* to the hands of the second watch. It follows that currents in opposite directions must repel each other.

(5) Lay the second watch face downwards on the top of the first. Obviously the hands travel in all parts of the circuit in opposite directions, and as the two similar poles are touching, they should repel each other.

(6) Lay the second watch face upwards on the first. The lower end of its axle, which represents a north-seeking pole, is upon the upper end answering to a south-seeking pole of the other. They should therefore attract each other. But it is evident that now the hands of both travel in the *same* direction throughout their course.

(7) It remains to seek the confirmation of this theory by experiment. Wind about 20 turns of covered wire round a box so as to make a square coil some 20 cms. each way, and after slipping it off, bind silk about the turns so as to keep them together. Bend the free ends down as represented in Fig. 23. No. 20 or No. 22 is suitable for this purpose.

Provide a support from which to hang the coil by a fine silk filament, *not spun silk,* which would twist, and let the free ends of the wire dip into two little cups containing mercury—doll's tea-cups will do very well. The wires from a battery are next to be brought so as to dip into the mercury in the cups, without touching the wires of the coil,

which will accordingly be traversed by a current, while free to swing in any direction.

A second similar coil, B, is now fixed near, but not touching it. There is no need for this to be movable, and the wires of a second battery may therefore be connected with it by twisting the ends together. A key should be included in the circuit. On closing the key of B, the coil A will swing round so that the part in which the current is flowing in the same direction as in the branch of

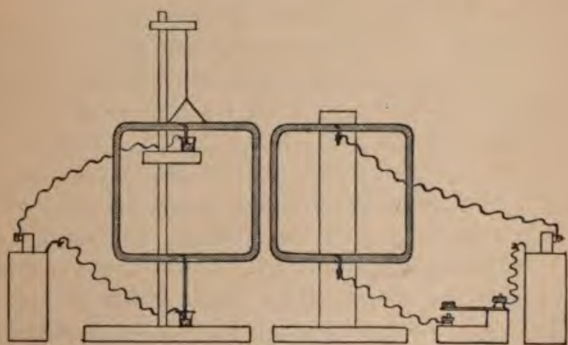


FIG. 23.

B nearest to it approaches B as closely as possible. But on reversing either battery, that side of the coil will be repelled, and the other, in which the current flows in the opposite direction, will take its place, proving that *parallel currents in the same direction attract, and in opposite directions repel, each other.*

(8) Currents not parallel, but at an angle to each other, are attracted if they are both travelling towards the apex of the angle, and repelled if one is travelling towards the apex

and the other away from it. In other words, the two circuits tend to swing round so as to become parallel and in the same direction.

To show this, place the coil B, in Fig. 23, above A instead of by the side of it. Then A can be rotated so as to stand at any desired angle with regard to B, and the consequent attraction or repulsion demonstrated. The action of a crooked wire is equivalent to that of a straight wire between the same points.

(9) There is another property of currents quite distinct from this. It is that, "*in a rectilinear current, each element of the current repels the succeeding one and is itself repelled.* In simpler language, a current flowing through a conductor tends to stretch it out longer. Bend a copper wire into a U shape and suspend it from a very delicate balance so that the two ends dip into two tubes containing mercury. Bring the wires from a battery provided with a key into connection with these tubes. The current will thus pass through a circuit free to become longer or shorter according as the copper bridge stands higher or lower in the mercury. Accordingly, on closing the key it rises slightly, falling again directly the current stops. A strong current is required.

(10) Lay an arc lamp on its side so that the lower carbon projects horizontally over the side of the bench. Remove the upper carbon and bind it on to the bared end of the cable by the middle with copper wire so that it may be horizontal when the cable is vertical. Hang it thus from the ceiling, and it will swing with tolerable freedom in spite of the stiffness of the conductor. Thus one carbon will be fixed while the other is free to move. Arrange the points very nearly in contact while the suspended one is at

rest, and switch the current on. A slight touch will cause the arc to form and the hanging carbon will be immediately repelled. If the two carbons should stick together they must be separated by hand, as the repulsion is not sufficient of itself to do so. This experiment should be deferred till the student is used to powerful currents.

Electro-magnets.—We have seen that a wire coiled in a spiral behaves as a magnet while it conveys a current. We now proceed to show how such a current will *induce* magnetism in a bar of iron.

(1) Procure a piece of iron rod about 2 cms. by 15 cms. long—a bolt will serve—and cover it with paper to protect the wire. Take sufficient covered wire on a reel to make a dozen layers on the bar, and arrange so that both ends of the wire can be got at from the first, to make the necessary connections. Wind one layer on the iron rod from end to end, and send a current through the whole. The bar will be distinctly magnetic, attracting other pieces of soft iron as long as the circuit is complete. Continue winding until you have a second layer over the first. The magnetism will now be twice as strong as it was. Observe that the current is the same as before, since it flows through the whole length of wire, but there is less on the reel, and twice the number of turns on the bar, which is termed the core of the electro-magnet. When a third coil has been put on the effect will be three times what it was at first, and so on with the rest until the "saturation" point is approached, when the increase will be slower and slower until it reaches the limit.

Proceeding with the current, the left hand end of the bar will be its north pole.

Another bar may be taken, bent into the shape of a U or

horse-shoe and coiled round with wire in like manner. The coils need not continue round the bend, as the effect produced by them is not so great there, but the direction must be the same as if they were continuous, otherwise both poles would be alike instead of one north and the other south.

If now a piece of soft iron is presented to the poles and the circuit closed, it will be attracted with great force and held as long as a current passes.

By attaching a spring balance to this piece of iron or "armature" we may ascertain what weight is required to detach it with a given number of cells in circuit, and the amount of current at the time may be measured by allowing it to pass also through the coils of the tangent galvanometer.

It is found that *the strength*[1] *of an electro-magnet is proportional to the strength of the magnetising current* (except near the point of saturation), and that *with the same current, the strength of an electro-magnet is proportional to the number of turns in its coils*, and is *independent of the thickness and material of the conducting wire*, save in so far as this affects the quantity of current which a given battery can send through it.

The next step towards the discovery of the possibility of the modern dynamo was made by Faraday in 1831. He found that when a magnet is moved near a coil of wire connected with a galvanometer, the needle is deflected, showing that electric currents are generated in the wire.

(1) In order to exhibit this, make a coil say fifteen cms. in diameter, consisting of about 100 turns or more of covered

[1] Not to be confused with "holding power," which depends on the shape of both magnet and armature.

wire, the ends of which are in connection with the terminals of a sensitive galvanometer placed at a distance of two or three metres. Next take a powerful bar magnet and wave it about, noticing if it has any effect upon the needle. If so, the operator must stand farther off, but he will probably find that an up and down movement will cause no appreciable disturbance, even when comparatively near. Now, holding the coil horizontally in the left hand, lower the magnet into it with the north-seeking pole downwards. The needle of the galvanometer will be deflected as long as the magnet continues to approach the coil, but will return to zero directly the magnet ceases to move, showing that a current is generated in the coil *not by the presence, but by the movement of a magnet near it.*

It remains to investigate the laws of this phenomenon. As the magnet is withdrawn, we notice that there is a fresh deflection of the needle, but in the *opposite direction.* This suggests that it would be well to ascertain in which direction these induced currents flow, whether they are invariably the same, how strong they are, and how long they last, and what are the conditions under which they are intense.

Merely to observe a fact, however curious or wonderful, is of comparatively little use. It is the systematic investigation of the modifications of the phenomenon under changes of condition—the finding out of the "how much" in each special case—that constitutes research and leads to useful results. "If fate would put some great discovery in my way," says the student, "I might emulate Ampère and Faraday." *It was not the discovery, but the investigation of it, that brought fame to these men.* A mere phenomenon, even the most striking, soon loses its interest, but the study

of the laws by which it is governed and the measurement of their effect affords the keenest and most lasting pleasure.

The general principle on which we proceed is this: Note carefully *all* the conditions of the original experiment, and *all* the characteristics of the result. Vary *one only* of the conditions, and any change that may result must be due to that. Proceed thus with each condition separately before attempting to determine the effect of any two combined. In this way Faraday and all the great experimenters went to work. If possible the student should read some of the original papers in which their discoveries were announced.

Thus in the case before us: We have seen that a magnet may be regarded as equivalent to a coil of wire in which a current circulates continually, so that when the north-seeking pole is pointing downwards the direction of the flow is "clockwise," as it is called. Repeat the previous experiment, holding the coil in the left hand so that its turns run also clockwise, and connect it in the same direction with the galvanometer coils. But how shall we know which way they turn? Put in a battery and try. Arrange it so that when the current runs clockwise round the coil, the needle is deflected towards the west. Then take out the battery. Now lower the magnet into the coil, the deflection is towards the *east.* Therefore the current induced in the coil is *in the opposite direction* to that which is supposed to circulate round the magnet. But as the magnet is withdrawn the deflection is westward. This shows that the induced current is now in the same direction as that of the magnet. Turn the magnet south pole downwards; its currents will now be counter clockwise, and will cause a westward deflection on approaching and an eastward deflection on receding from the coil. From these experiments

we learn that the induced current is "inverse" during the approach of the magnet, and "direct" while it recedes, but ceases while the magnet remains in any given position.

(2) Since it is evidently not the *presence*, but the *movement* of the magnet that causes currents, try the effect of varying the velocity of the motion. Insert the magnet slowly—the deflection is small, but of course lasts longer. Withdraw it quickly—the swing is much greater, but is sooner over. Evidently the E.M.F. of the current generated depends on the velocity of the movement.

(3) Hold the magnet at a fixed distance from the coil, and suddenly turn it end for end. This is equivalent to removing the north pole to a greater distance, and bringing the south pole nearer. In which direction would the galvanometer be deflected? Fasten the magnet to a wheel, and make it revolve rapidly so as to present first one end and then the other to the coil. There will thus be generated a series of short sharp currents in opposite directions, which may be felt as shocks by laying hold of the two ends of the wire if the coil is sufficiently long, and the magnet a strong one. The nearer it is to the coil, and the faster it spins, the greater the effect. It is, in fact, an "alternate current" magneto-electric machine.

(4) But the earth is a huge magnet—can we not make it act upon the coil so as to produce a current? Obviously we cannot remove the coil to a sufficient distance from it to make the slightest difference, nor can we reverse the poles, but we can turn the opposite face of the coil towards the north. Set the coil vertically, and suddenly twist it halfway round. There will be a deflection of the galvanometer due to the current produced by revolving it in the earth's magnetic field. The quantity of electricity thus generated

is constant for a coil of given size, and the method is used in measuring the magnetic qualities of different samples of iron.

(5) If a magnet may be regarded as having currents circulating round it, a coil of wire conveying a current should act as a magnet, and induce currents in another coil when it is brought nearer to or removed farther from it. Take a coil of many turns, connect it with a battery capable of sending a strong current through it, and repeat the previous experiments, using this coil instead of the magnet. When the two are brought nearer together, an inverse induced current is generated in the other, and while they are being separated the galvanometer shows a direct current. Thus we find that a coil of wire acts in all respects as a magnet.

(6) Stop the battery current in the second coil. Its movement now produces not the slightest effect on the galvanometer. It has ceased to act as a magnet, and therefore cannot generate induced currents. But by closing the circuit we can make it into a magnet at any instant. What would happen therefore if instead of bringing the wire conveying a current up to the coil, we were to place the two close to each other, and then close the circuit? This was the experiment that Faraday made in 1832.

(7) Lay the second coil on the top of the first, and suddenly close the battery key. The galvanometer will be deflected for an instant, showing that there was a momentary induced current in the opposite direction to that of the battery. When the needle has come to rest, open the key sharply. The needle will start suddenly in the opposite direction as if it had received a blow.

But as long as the current flows there is no deflection, because it then acts like a magnet at rest.

(8) With a sensitive galvanometer the student may try the following experiments. Let one of the battery wires dip into a basin of solution of copper sulphate, in which a second wire, leading to the inducing coil, is immersed. The current will then pass through the liquid, and by increasing the distance between the two wires, the resistance may be made considerably greater, thus diminishing the current without ever completely stopping it. This will cause a direct induced current, while on bringing the two wires nearer, and thus increasing the flow in the inducing circuit, the galvanometer will show an inverse induced current in the other coil. The effect will be not so great as when the current is started or stopped with the battery key. We may sum up the results as follows:

Two parallel currents in same direction *attract* each other. If a wire conveying a current is forcibly brought nearer to another wire, it induces in it a current *in the opposite direction.* Two parallel currents in opposite directions *repel* each other. If a wire conveying a current is forcibly removed farther from another wire, it induces in it a current *in the same direction.*

Increasing the intensity of the current in a wire has the same effect as bringing it nearer, and *vice versa.* To start a current is manifestly the same as to increase its intensity from zero, and *vice versa.*

A magnet acts in all respects as though a current were continually circulating round it, the north-seeking pole being always to the left of the current. A coiled conductor while conveying a current acts exactly as a magnet, the north-seeking pole of which is to the left of the current.

CHAPTER XI.

ELECTRICAL APPLIANCES.

The Bell.

WE are now in a position to understand some of the practical applications of electrical science. Among the simplest is the bell, struck by a hammer attached to the armature of an electro-magnet. This is excited by a small battery—generally a Leclanché or a dry cell, as these require no looking after, and there is no waste from local action—and the signal is given by connecting the two wires. This is conveniently done by means of a "push," which is a kind of key. One of the wires is connected with a little metallic stud at the back of the case, and the other with a curved piece of brass which acts as a spring, standing clear of the stud until it is pressed down upon it by pushing the well-known button. The two wires forming the circuit may be of any length, provided the rest of the apparatus is made to correspond. That is to say, if the line wires have a high resistance, the electro-magnets must be wound with many turns of wire, or else the E.M.F. of the battery must be increased. Obviously, the battery may be placed at the far end, or at any convenient part of the circuit, but there is

this advantage in having it near the bell, *viz.*, a number of pushes can then be fixed at intervals along the wires, and any one of them will ring the bell by completing the circuit. Such an arrangement will give a single stroke each time the button is pressed. But this would not be sufficient to attract attention. Accordingly, the bell is made to ring continuously by the device shown in Fig. 24.

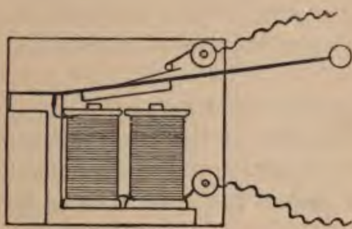


FIG. 24.

One end of the coil is attached to the spring of the armature, which while at rest presses against the adjustable screw connected with the line wire, thus allowing the current to pass directly the circuit is completed by pressing one of the pushes. But the first effect of the current is to attract the armature, and in so doing to break the circuit by drawing it away from the screw. This causes the electro-magnet to lose its power, and consequently the spring flies back again and comes once more in contact with the screw. A second current passes and the bell is struck again, and so on, the armature vibrating to and fro as long as the circuit is completed at the distant push, thus producing the well-known trembling sound.

Simple Circuit with "Earth."—Any conducting substance, such as the gas or water pipes, will serve for the one

half of a circuit, all that is necessary being that the other half should be insulated from it, so that the current cannot take any short cuts, but must go to the far end of the circuit. Moreover, the soil is always sufficiently moist to act as a conductor, which makes up for its high resistance by its dimensions, if the surface of contact is large enough. Accordingly, one wire from the battery is joined to a large plate of metal or a load of coke buried in the ground, and the other, after passing through the coils, is carried to the push at the far end of the line, and thence to a similar buried plate or "earth."

In order to make several bells ring simultaneously from one push, it is usual to put the bells, the resistance of which should be about equal, in parallel circuit, with one battery situated by the push. The cells have to be arranged for quantity.

Single-stroke bells may be arranged in series, so as to ring simultaneously, but tremblers require careful adjustment to make them work well thus, since the first armature that moves breaks the circuit and stops the current before the rest are sufficiently magnetised to ring. Sometimes Shunt bells are employed in such cases.

Relays.—With a long circuit it may not be convenient to employ currents strong enough to actually ring the bell. In this case an electro-magnet is used, the armature of which forms part of a key or push, with a very weak spring. This key is placed in the circuit of the bell, which is provided with a battery of its own. On pressing down the distant push the armature of the relay is attracted, closing the local circuit and thus ringing the bell. The first relay may, if the distance is very great, be used to actuate a second, and so on.

Burglar Alarms are sometimes worked on this principle, but the relay is made differently. Its armature acts as a trigger by which the key of the local bell-circuit is held open. A special form of push is fixed by each door or window, so that if anyone of them is opened, contact is made, the armature of the relay attracted, and the lever let go, closing the key and causing the bell to ring till somebody stops it. A switch is provided to cut off the battery during the daytime.

Hot-House Alarms.—These indicate when the temperature rises above or below a certain amount. Instead of a push, they are provided with thermometers so constructed that when the mercury reaches a certain position it comes in contact with a platinum wire, which forms one part of the circuit, the mercury being connected with the other side. Thus a current is sent either by the maximum or minimum thermometer to a relay which rings a bell. Some forms have, instead of a thermometer, a strip composed of two ribbons of different metals, which expand unequally with a rise of temperature. This bends to one side or the other, according as the house is too hot or too cold, and makes contact, not only ringing a bell, but throwing the vane of an indicator to the right or to the left, according to which side the strip of metal touched.

Bell Circuits with Indicators.—The indicator is simply an electro-magnet working a trigger, which lets fall an index of some kind. Many varieties are made. Some set a kind of pendulum swinging—others have an arrangement by which an electric current replaces the index. The usual disposition of the circuit is as follows.

The battery wire from the copper is carried from room to room and connected to one side of each push. The

wire from the zinc is carried through the bell magnets to one side of each indicator, and a separate wire leads from the other side of each indicator to the other side of the corresponding push. Thus each push rings the same bell, but actuates a different indicator. Obviously the single wire from the copper performs the functions of an "earth," which would, in fact, do equally well, only it would be so much more cost and trouble to connect each separate push with a sack of coke buried in the ground.

Electric Telegraph.—The object of the bell is to call—that of the telegraph to converse. The bell must be loud to attract attention; the telegraph needle must be light to convey complex signals quickly. Hence, whereas the bell acts merely on the principle of pull-and-let-go, paying no heed to polarity, the telegraph is modelled rather on that of the galvanometer, and its needle is deflected to the right hand or the left, according to the direction of the current. Here again we have an illustration of the development of one function at the expense of the rest. The telegraph instrument is not required to measure the intensity of a current, but only the fact of its passing and the direction, and to respond quickly to a very small impulse; so the coils are flattened to bring them close to the needle, which is hung, not horizontally, but vertically, like the pendulum of a metronome. In order that the eye may follow its movements rapidly, a pin is fixed on either side to stop it at a certain angle. It was soon found that messages could easily be read by the sound of the needle striking against these stops; so one of them was purposely made to give a different note. Hence the familiar tapping of the post office instruments. The tapper, Fig. 25, is ingeniously contrived. There are two keys, of which one is connected

with the line, and the other to earth. When not in use they both make electrical contact with the cross strip above

FIG. 25.

them, which is joined to the zinc of the battery. Thus both the line wire and the earth are connected with the zinc until one of the keys is moved. Beneath them is a similar strip leading to the copper of the battery. If one key is depressed, the current runs out through earth and back by the line wire; but if the other is depressed, it passes out by the line wire and back through the earth to the zinc, *i.e.* in the opposite direction.

Another type is the Morse system, by which the message is printed. Here the necessary variety is got, not by recording the direction of a current, but by making a distinction between long and short duration. The telegraph signal works a relay, and this actuates an electro-magnet, the armature of which carries a style. When a current passes, the style is brought down on to a paper tape moved by clockwork, making a long or short mark upon it according to the duration of the current. Short marks or dots are taken as equivalent to a beat of the top of the needle to the

left, and long lines or dashes correspond to a beat of the needle to the right. The following is the code in use :—

A . —	K — . — .	U . . —
B — . . .	L . — . .	V . . . —
C — . — .	M — —	W . — —
D — . .	N — .	X — . . —
E .	O — — —	Y — . — —
F . . — .	P . — — .	Z — — . .
G — — .	Q — — . —	Full stop . . . . . .
H	R . — .	Repetition . . — — . .
I . .	S . . .	Hyphen — . . . . —
J . — — —	T —	Apostrophe . — — — — .

Two persons using this code may communicate at considerable distances with the aid of flags, or even umbrellas, or by simply waving the arms.

Another type is the dial telegraph. The letters of the alphabet are arranged round the dial with 27 divisions, the uppermost of which is left blank. An index, connected with a ratchet wheel, which can only revolve in one direction, points to each letter in succession. An electro-magnet actuates a pawl, so that every time the armature is attracted the ratchet wheel is pulled forward one notch. Thus to signal the letter A, the operator at the distant station might press the key once. Supposing the next letter of the message to be D, he must give three more taps, when the index would move on to B, C, and D, where it would stop. This, however, would be a dreadfully tedious process. But the speed with which an electro-magnet works is so great, that a very simple mechanical device is available. The sending key consists of a brass wheel with 27 teeth, turned

by a handle working over a dial marked with letters exactly like that of the receiving instrument. A metallic spring, connected with one side of the battery, presses up against the edge of the wheel so as to touch only one tooth at a time. Another spring, joined to the line wire, makes continual contact with the axle. On turning the wheel once round, 27 shocks are sent in rapid succession through the wire, causing the electro-magnet at the far end to make 27 distinct pulls on the pawl, thus turning the idex of the receiving instrument completely round. To signal D, it is only necessary to move the handle to that letter. Four teeth rub past the spring, four shocks are sent, the ratchet wheel is pulled round four notches, and the index stops also at the letter D. To signal O, the handle is moved on to that letter, and the index keeps pace with it and stops likewise at O, and so on.

At the end of a word the handle is turned once round, stopping at the zero. To indicate a full stop, two complete revolutions are made, and for the conclusion of the message, three. It is only necessary to set the instruments before commencing, so that both point simultaneously to zero. This apparatus is slower than the ordinary form, but needs no special training to use it.

The tape machine, which prints the message in ordinary type, is a farther elaboration of the same principle. For a description of it the student must consult larger works.

Most of the telegraph lines from one town to another are carried overhead on insulators attached to poles, but in large cities they are now generally laid under the pavements. In this case the wire has to be protected by an insulating cover-

ing, and is called a cable. Cables which have to pass under the sea are made specially strong.

The actual conductor consists of a strand, about three millimetres in diameter, composed of a number of copper wires, so that if one should break, the rest would convey the current past the defect. This part is thickly coated with gutta-percha, and is called the "core." Outside it is a layer of white tape laid lengthwise, and over this a brass ribbon is wound spirally to protect the core from the "teredos," which would otherwise bore their holes in the soft insulating medium. Outside the brass comes a layer of black water-proof tape, and over that a number of strands of yarn. It is then completely covered round with steel wires to give it strength, and to prevent these from rusting they are wound over with two layers of tarred tape, one in a right handed and the other in a left handed spiral.

The cable is then coiled in great tanks filled with water, and its insulation tested, by connecting one pole of a battery with the water in the tank, and the other with one end of the conductor, and using a very delicate galvanometer. If this shows the smallest deflection, it indicates a "pinhole" in the insulator by which a current leaks through.

Cables are thus tested at frequent intervals while they are being made, and again during the process of laying down. But if a fault should escape notice or develop when the line is in use, it can not only be detected, but its position located by this same method. For the resistance of a cable is easily measured, and of course carefully recorded. Let us suppose it to be 5,000 kilometres long, with a resistance of 2·5 ohms per kilometre. If by accident this cable should be broken in two, the contact of the sea water with the ends will make a perfect "earth" or return circuit

of no resistance from each. As soon as it is discovered that signals no longer pass, the electricians at each end take the resistance.

For example, let it be 10,000 ohms at the English, and 2,500 ohms at the American end. Then, since the entire 5,000 kilometres must have a resistance of 12,500 ohms, two things are evident—(1) that the fracture is complete, making a perfect "earth" to each portion, and (2) that it is broken into two parts, one of which, with a resistance of 10,000 ohms, is $\frac{4}{5}$ths, and the other $\frac{1}{5}$th of the entire cable. The break must therefore be sought 1,000 kilometres from the American shore.

Next, suppose that the failure is not complete, but that on testing for resistance it is found one day to be less than 12,500 ohms. This shows that there must be a leakage. The following method of finding out the whereabouts of it, is the most easy to explain without using mathematical formulæ. The operator in America disconnects his end of the cable, and his colleague in England finds that he still has a circuit; but with a resistance of 10,000 ohms. He now disconnects the English end, and a similar test is made in the American office. This time the resistance is 11,000 ohms. The sum of these is 21,000 ohms, *i.e.* 8,500 ohms more than the total resistance of the cable.

The question is, what does this mean? There must be a pinhole through which the current passes, but not very freely. First, we have to determine the unknown resistance of the fault.

The total is made up as follows:—

Resistance from America to the fault	= unknown
Resistance of the fault itself ...	= unknown
Total by the test, ...	11,000 ohms

Resistance from England to the fault	= unknown
Resistance of the fault itself ...	= unknown
Total by the test, ...	10,000 ohms
Grand total, ...	21,000 ohms

But this grand total is evidently made up of the resistance of the entire cable taken in two unknown parts, *plus* that of the fault taken twice over.

Now the resistance of the whole cable was 12,500 ohms, so that *half* the excess, namely 4,250 ohms, is the resistance due to the fault. Subtract this from the tests at each end and we have—

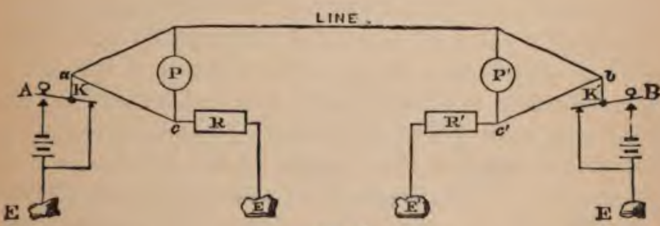
American test, ...	11,000 ohms
The fault, ...	4,250 ohms
Resistance of cable up to the fault,	6,750 ohms

English test, ...	10,000 ohms
The fault, ...	4,250 ohms
Resistance of cable up to the fault,	5,750 ohms

And as the resistance of the cable is $2\frac{1}{2}$ ohms per kilometre, it is easy to calculate that the leakage occurs 2,300 kilometres from the English end. In practice the calculations are more complicated, but this example will serve to illustrate the main principle.

Duplex Telegraphy is one of the most interesting developments of electrical science, by means of which two perfectly distinct messages can be transmitted simultaneously from

the opposite ends of a wire without interfering with each other. There are several ways of doing this, of which Fig. 26 represents the simplest. The two circuits are arranged alike at each end. P and P' are galvanometers (*i.e.* telegraph instruments), R and R' are variable resistances, and E represents earth. It will be observed that each station constitutes a Wheatstone's bridge. Thus on the left hand *a* C and *a c* correspond to the branches A and C in Fig. 10; R E answers to D, while the branch B of Fig. 10 is made up of the line, the receiving station, and the earth. So that if the resistance of R is made to balance that of the



FIG, 26.

line, etc., the galvanometer P is not deflected by any current from the battery at A. But a current coming in along the line from the other station reaches A and finds a Wheatstone's bridge there, with this difference—the telegraph instrument does not occupy the galvanometer position, but forms *one of the arms of the bridge*, and is therefore deflected. Thus the problem is solved. The sender's instrument is *not affected by currents from his own battery*, but only by those which come in from the line, and conversely *his* signals deflect the needle at the other station.

If he wishes to read his own messages he must insert another telegraph instrument between say R and E.

The Telephone must be classed among signalling instruments, of which it is perhaps the most wonderful. The principle may be easiest understood from Graham Bell's first form.

A steel bar-magnet 10 cms. long and 12 mms. in diameter has a short piece of iron of the same diameter attached to one end so as to form one piece with it. Round the iron is a coil of many turns of fine wire. The whole is fixed in a wooden tube across the end of which is a diaphragm like a drum-head of very thin sheet iron. The magnet is set so that its iron pole comes very near the diaphragm without touching it. As the thin sheet of iron is made magnetic by induction, every time it approaches the pole it causes an inverse current to circulate in the coil, and a direct one as it recedes. But it is obvious that if we couple up two such telephones together, the current induced in one by the approach of the diaphragm can be sent round the coil of the other in such direction as will cause the iron core to attract the diaphragm near it, and in that case the opposite current, generated as the diaphragm of the first recedes, will cause that of the second to recede also, not with the same force, for we cannot prevent a great deal of the power from being lost, but still sufficient to cause the motions of the second diaphragm to be a faithful copy on a small scale of those of the first.

Now it is well known that every musical sound is due to rhythmical vibrations, the pitch of the note being determined by the number per second. Moreover, the tone, or clang-tint, as the Germans call it, of the note depends on other vibrations of greater frequency,

called harmonics, associated with it so as to form a chord. Still farther, the vowel sounds and consonants of speech are found to be produced by rhythmical vibrations of different frequencies combined in definite though complex proportions. Since therefore the electrical currents generated by the movements of the one diaphragm cause the other to execute precisely similar movements on a smaller scale, it follows that every musical note sounded near one instrument will be given out by the other with the same pitch and clang-tint, and every vowel sound and every consonant will also be reproduced. But as speech is made up of musical notes, and intonations, and vowels, and consonants, it follows that even speech will be reproduced. This is the theory of the telephone.

The phonograph is not to be confounded with it, being a purely mechanical, and not an electrical instrument. In it the diaphragm merely actuates a sharp style which indents, upon a moving, yielding surface, such as wax or tinfoil, a record of the vibrations, which, when it is caused to pass once more under the style, makes it move up and down exactly as before, thus communicating a similar set of vibrations to the diaphragm.

The Microphone acts on a different principle. When two conductors are placed lightly in contact, the slightest touch causes them to separate slightly, thus stopping for an instant any current that may be passing. Even if they do not actually separate, the change of pressure produces an alteration in the resistance of the contact, and consequently the strength of the current. This effect is greatest when both conductors consist of carbon. Two pieces of this substance, one attached to a thin piece of wood like a sounding-board, and the other laid

loosely against it, are arranged so as to form part of the circuit of a battery, the wires from which are connected with a telephone. Words spoken near the sounding board cause it to vibrate, and thus give rise to a series of fluctuations of the current. But reducing the strength of a current has the same effect as removing an induction coil to a distance, and *vice versâ*. It follows that every word spoken near the microphone will be reproduced in the telephone, and as considerable currents can be employed, the sounds will be even increased in intensity. The tread of a fly's foot as it crawls over the instrument is heard with startling distinctness.

In the Gower-Bell telephone the sending part of the apparatus consists of such a microphone, in circuit with the primary of an induction coil. The line wire is connected with the secondary, and the induced currents caused by the variations in the strength of the main current passing through the microphone produce the necessary vibrations of the diaphragm of the receiving telephone.

Telephones are of great use for other purposes besides transmitting speech. They may be employed as indicators to show when a circuit is complete. For this purpose a telephone is simply included in the circuit at any convenient point, and on opening or closing the battery key the operator hears a "tap" if all the connections are properly made.

The Induction Balance of Hughes' is an example of their use. It consists of two induction coils with movable secondaries, fixed about thirty-four cms. apart. The secondaries are connected on one side by a wire, and on the other by a telephone. The two primaries are joined up in series with a battery and an in-

strument called the interrupter. This consists of a cog-wheel which can be made to revolve rapidly against a strip of brass connected with one wire, while the other presses against the axle of the wheel. The interrupter is, in fact, a special form of key for the purpose of sending a rapid series of short currents through the primaries, without making much noise. These cause induced currents in both the secondaries, but the connections are so made that those from the one are opposite in direction to those of the other. They will therefore be completely neutralised if we can make them of exactly the same strength. But we have seen that induced currents can be weakened by withdrawing the secondary to a greater distance from its primary, and strengthened by inserting a core. First then, we weaken the stronger of the two by drawing it farther out until the induced currents exactly balance each other. When this point is reached, turning the interrupter produces no sound in the telephone. Inside each secondary instead of a core is a little wooden cup serving as a support. In one of these we put a fragment of copper wire, and turn the interrupter. Immediately the telephone emits a sound, because the metal acts as a "core" and alters the action of that coil.

The position of the copper wire inside the secondary influences its effect, and each metal has not only a different inductive power, but gives a different sound, and to obtain silence we must "balance" by pushing in the other coil, or by placing in its cup an exactly similar piece of metal. Two coins of the same value are seldom sufficiently alike, but if one is base the fact will be announced with unmistakable distinctness.

Kohlrausch's Method.—To find the internal resistance of a battery, let it form branch D of a Wheatstone's bridge,

substituting a telephone for the galvanometer, and connecting the secondary of an induction coil with the terminals marked "zinc" and "copper." The induction coil should be placed in another room. While it is working a buzzing sound will be heard in the telephone. When a perfect balance is obtained, the telephone will be silent. This is the only reliable method of measuring the resistance of an electrolyte.

Self-Induction or Inductance.—(1) Having laid hold of one of the wires from a Daniell's cell, touch the other with the finger. No effect will be perceived even when the hands are moist. Lead the current through a long wire closely coiled up —*e.g.* just as it was bought—and although it must necessarily be weakened by the extra resistance, a slight shock will be felt on completing the circuit with the hand, and a stronger one on letting it go. If the effect cannot be felt with the fingers, the two wires may be touched with the tongue, which is more sensitive. A more powerful shock is given if a large piece of soft iron is placed in the centre of the coil, and the experiment succeeds well with an electro-magnet. The explanation is, that a current in any wire, as it starts, induces in a neighbouring wire a momentary current in the opposite direction, and as it stops, one in the same direction. Each turn of the coil therefore, when the circuit is closed, induces an opposing current in the neighbouring turns, and when the flow is stopped, induces a similar direct current. This is known as the extra or break current, and the "shock" is due to it. Some of the "medical coils" are made on this principle.

The Induction Coil and the Transformer.—But the true induction coil, invented by Ruhmkorff about 1851, consists of two wires, namely, the primary, of low

resistance, and therefore stout and of comparatively few turns, and another, called the secondary, very long and fine. The primary is coiled on a hollow bobbin, the tube of which may be of cardboard, as the E.M.F. of the battery employed is not likely to be high enough to require very perfect insulation. The wire is coiled on this in several layers, and the two ends connected with a pair of terminals. The ends of the bobbin should project very little above the wire. As it is convenient for many purposes to be able to remove the secondary from the primary, either partially or wholly, the secondary wire should be wound on a separate bobbin, the tube of which is large enough for the primary to be slipped inside. But as the object is to get a high potential, the insulation must be much more perfect. The bobbin may be made wholly of ebonite, or with a glass tube and ebonite ends. The wire is slipped through a small hole in one of the ends and wound on with the utmost care, the bobbin being mounted for the purpose on a wooden axle furnished with a handle and fixed in temporary bearings. As each layer is completed it must be coated with shellac varnish and allowed to harden. Roughly, the E.M.F. of the induction shock will bear the same proportion to that of the battery as the number of turns of the secondary bears to that of the primary, but the quantitative law of the action cannot be properly treated in a work like the present. When the bobbin is full, the wire is put through a hole in the end plate and carried to a terminal. It remains to describe the core. This consists of a bundle of soft iron wire about the thickness of packthread, cut into lengths and packed tightly into a bundle that will just slip inside the tube of the primary.

The student may now observe the properties of the coil,

Connect the secondary with a galvanometer, and the primary with a battery and a key. Close the key. There is a momentary deflection indicating an inverse current. Open the key. The deflection is stronger and in the opposite direction, being due to the direct induced current of the break. Take away the iron core from the primary. The effect of opening and closing the key is the same as before, but weaker. Push the core half in, and notice the increased strength of the shocks. This shows the use of having a core. Push the core right in and pull the bobbin of the secondary half off the primary. The deflections are much smaller. Remove the secondary to a still greater distance, and they will become scarcely discernible. Now put a bar of iron through the two bobbins, so as to have one at each end of it. The induced currents in one coil due to make and break of the battery circuit of the other, will be plainly seen. Next, bring the two coils close together, and set the secondary bobbin at right angles to the primary. Whether the iron core is in or out, there will be no induction whatever. On gradually turning the coils round so as to bring them parallel, the deflections will begin to appear. These three methods, *viz.*, drawing out the core, removing the secondary to a distance, and setting the secondary at an angle to the primary, are all employed in order to adjust induction shocks to any required degree of strength.

Such a coil may be made of say 100 turns of No. 20 in two layers for the primary, and from 3,000 to 5,000 turns of No. 30 or No. 36 for the secondary.

But for the experiments now to be described it is better to buy a coil of the usual type with fixed core and bobbins. The proportion of turns on the secondary being much greater,

special care has to be taken with the insulation. The E.M.F. produced is so high that when the terminals of the secondary are brought within a certain distance, depending on the size of the coils, a spark passes each time the battery circuit connected with the primary is broken. As has been already shown in the account of induction currents, no effect is produced in the secondary circuit while there is a steady current in the primary, any more than if there were no current at all. It is only *during change*, *i.e.* rise or fall of the primary, that there is an inverse or direct wave of current in the secondary. It is necessary therefore to provide means for rapidly making and breaking the battery circuit. This is effected by an arrangement precisely like that of an ordinary electric bell. The iron core encircled by the primary becomes strongly magnetic directly a current passes. It attracts a small armature, called the hammer, attached to a spring, which while at rest presses against the point of a small platinum-tipped screw connected with the wire from the battery. The pathway for the current is from this screw, through the spring of the armature to the primary coil, and thence by a kind of key called a "commutator" to the other side of the battery. The commutator is in reality a switch by which the current can be stopped altogether, or sent in either direction. The moment a current passes, the core becomes magnetic—attracts the hammer, and in so doing breaks the circuit and loses its magnetism. The spring instantly flies back, makes contact again, and is again attracted, vibrating at a rate conditioned by the weight of the hammer, the strength of the spring, that of the current, and the amount of free play allowed the hammer by the position of the platinum-tipped screw. The closer this is set, the more rapid is the movement. Each closure of the

circuit produces an inverse current in the secondary, and each break a direct induced current.

As the self-induction of the primary is considerable, there is a powerful extra current at break, causing a spark at the hammer contact, which, with a strong battery, is very hot, and would rapidly burn away the platinum.

Moreover, this spark as it were prolongs the breaks, and prevents that sudden cessation of the current so essential to produce a powerful induction effect. Accordingly Fizeau introduced what is called the condenser. This is practically a Leyden jar, or rather a battery of coated plates of large electro-static capacity (see p. 11). It consists of a number of pieces of tinfoil separated by two thicknesses of paper soaked in melted paraffin, the sheets of paper being about 5 cms. larger each way than the tinfoil, so as to afford a good insulating margin. The alternate sheets of tinfoil project beyond the paper at opposite ends, and are joined to a pair of binding screws to which the primary wires are attached. When the battery circuit is broken, the electricity, instead of sparking at the hammer, flows into this condenser, charging it. But as the terminals are still connected by the primary coil, this charge immediately rushes back again, thus producing not merely a cessation of the original current, but a return wave in the opposite direction, and inducing in the secondary a current in the same direction as that due to the break, and so adding considerably to its effect. Moreover, this return oscillation helps to demagnetise the iron core more suddenly, and in this way also increases the E.M.F. of the induction shock and shortens its duration.

It must be remembered that the quantity of electricity induced at the make and break of the primary is the

same. The induced current at the make is of a lower E.M.F. and lasts longer; that at the break is shorter and more intense. If the two poles of the secondary are separated by an interval of air, usually only the break spark, or direct current, has sufficient intensity to pass.

It is necessary to avoid separating the poles beyond a certain distance, otherwise the spark, finding no passage, may strike through the coil itself and destroy the insulation. For where once a spark has passed, others will follow. With a good battery a perfect torrent of sparks is discharged between the terminals of the secondary, producing a brilliant light and crackling sound. As is the case with the Leyden jar, plates of glass may be perforated by their means. If the two poles of the secondary are connected with a Leyden jar it will become charged, the sparks will be less frequent but more dense, and the report made by each will be louder. If the terminals are made to dip into dilute acid, then, according to the strength of the exciting current, mixed gases may be evolved from one or both poles. If they are led into a strong tube containing hydrogen and oxygen, these gases will combine, owing to the great temperature of the sparks, with detonation if mixed in the right proportion. Generally speaking, gases tend to enter into combination under the influence of the induction spark.

Another beautiful series of experiments can be made with Geissler's tubes. These are glass tubes furnished with a platinum wire fused into either end, filled with some gas, and then very nearly exhausted. For although all gases at ordinary pressures have an extremely high resistance, and a perfect vacuum is a perfect insulator, yet at a pressure of one or two millimetres, high tension currents pass with ease, producing curious effects. Sometimes the whole tube is filled

luminous, although not in connection with either. When one terminal was connected with a glow-lamp held in one hand, while the other hand grasped a large metal ball attached to the other terminal, the interior of the lamp became filled with a soft luminosity—the currents passing through the body of the experimenter without causing any unpleasant sensation.

Another question will probably occur to the student. What effect—if any—would be produced by using an induction coil the wrong way, *i.e.* sending an alternate or an interrupted current through the *secondary*, and leading off from the primary? Put half-a-dozen or more Daniell's in series on to the secondary, and lay hold of the ends of the primary. Probably you will feel nothing. Touch the two wires against your tongue—possibly you may just be able to perceive the shock on opening the battery circuit. Connect the primary with a *low-resistance* galvanometer and you will at once get deflections both on opening and closing, just like those of the *sensitive* galvanometer when it was connected with the secondary and the battery was on the primary. Next attach to the primary a piece of very fine platinum wire, or a low-resistance glow-lamp, and send the alternate current from a magneto-electric machine through the secondary. The platinum will become hot, or the lamp will glow. These experiments indicate that currents are induced as before, but of *different quality*. A low-tension interrupted or alternate current of large quantity in the primary, produces high-tension alternate currents of small quantity in the secondary, and conversely; high-tension alternate currents of small quantity in the secondary induce *low-tension currents of large quantity in the primary*. An induction coil used in this way is called a "transformer."

Transformers are of three types—closed circuit, open circuit, and motor transformers. The latter will be described in the chapter on Dynamos. The Mordey transformer has a closed magnetic circuit. It consists of two rectangular coils—a primary of thick wire, and a secondary of fine wire laid one on the top of the other, and completely surrounded inside and out with a core built up of thin iron plates. Fig. 27 represents it in section, the full

FIG. 27.

lines showing the plates that enclose the coils, and the dotted lines those that pass through the centre. Swinburne's "Hedgehog Transformer" is like an ordinary induction coil with a very long core, the wires of which are bent up at each end so as to form a kind of bristly brush. The magnetic circuit is said to be "open," because the iron does not encircle the copper wires. An alternating current of high tension is sent through the secondary or fine-wire coil, and a low-tension alternating current of correspondingly larger quantity is given off by the primary. Transformers, like induction coils, only work with an interrupted, or better, an alternate current, and depend therefore for their use on a specially constructed dynamo.

CHAPTER XII.

THE DYNAMO.

When Faraday discovered in 1831 that the movement of a magnet near a coil induces currents in it, he at once perceived that this might be a means of generating electricity. In the following year a machine for this purpose was invented by Pixii, and made in Paris. A horse-shoe magnet was caused to revolve in front of two small coils in which alternate currents were generated as the opposite poles approached and receded from them.

But as the magnet, to be strong, must of necessity be heavy, it was found better to keep it stationary. Accordingly Clarke introduced the plan of having two coils fixed to an axis on which they could revolve past the poles of a magnet. This machine is still sold for medical purposes, and its appearance is familiar to most people.

To change the alternating current into a continuous one, it is provided with what is called a "commutator," the principle of which is described farther on.

To trace the evolution of the modern dynamo from this machine is both interesting and instructive. In the first place, we must bear in mind that experiments are necessarily tedious and costly when they involve not merely the arrange-

ment of a few wires and beakers, but the construction of a machine.

Accordingly, it was not until the stimulus of a demand for cheap electricity was felt, that much progress was made. In 1842, an electro-magnetic current was tried at Woolwich for electro-plating, and in 1850, Nollet in Brussels invented a large machine for the purpose of producing the electric light in lighthouses. But these were only Clarke's machines of greater dimensions, and with many magnets and armatures instead of one.

Siemens made the first real advance in 1856, when he invented the armature represented in Fig. 28. It consists of a cylinder of iron of any desired length from a few cms. to a metre, with a deep groove in each side and round the ends in which the wire is laid, as string is wound on a netting needle. It thus resembles a number of short magnets arranged side by side, but all enclosed in a single coil instead of being wound separately. When it is magnetised by the passage of a current, the poles are not at the ends, but on the two faces all along the sides. The idea was that as the

FIG. 28.

magnetic field is most intense close to the poles, it is better that the coils should never move far from them, and with a long armature of this shape a number of horse-shoe magnets could be fixed in a row so as all to act at once on the coil

as it revolved between their poles. But another result followed, which was hardly realised at the time.

This invention broke down the notion that a coil must be circular, and a magnet either a straight bar or a horse-shoe, and by its very novelty suggested the possibility of fresh novelties.

It is interesting to trace the chain of ideas. In these machines currents are generated by moving a coil under the influence of a magnet. We get a strong current from a more powerful magnet. But the strongest of all magnets is the electro-magnet. Why not use it instead of a permanent magnet? But to do this we must employ a battery. Shall we get more current from the machine than the battery itself would give? Can the cause be greater than the effect? No; but in this case the cause is not the magnet, but the work done in making the armature revolve, and therefore we may hope to get more current from the machine than the battery could produce. Still we have given up the principle for which we were striving. We desired to get a current by mechanical, apart from chemical means, and we have gone back to the battery. Is there no means of keeping to our principles? Since a current is a current, however it may be generated, why not send the current from a small magneto-electric machine round the coils of a large electro-magnet, between the poles of which a large Siemens armature revolves? Such an idea would not readily occur to a man who had to buy his apparatus, for lack of means to carry it out, but it came to the mind of Mr. Wilde, and in 1865 he constructed the machine shown in Fig. 29. The upper part is a Siemens magneto-electric machine complete in itself. P is a "battery" of permanent magnets, with soft iron pole-pieces C C, between which the

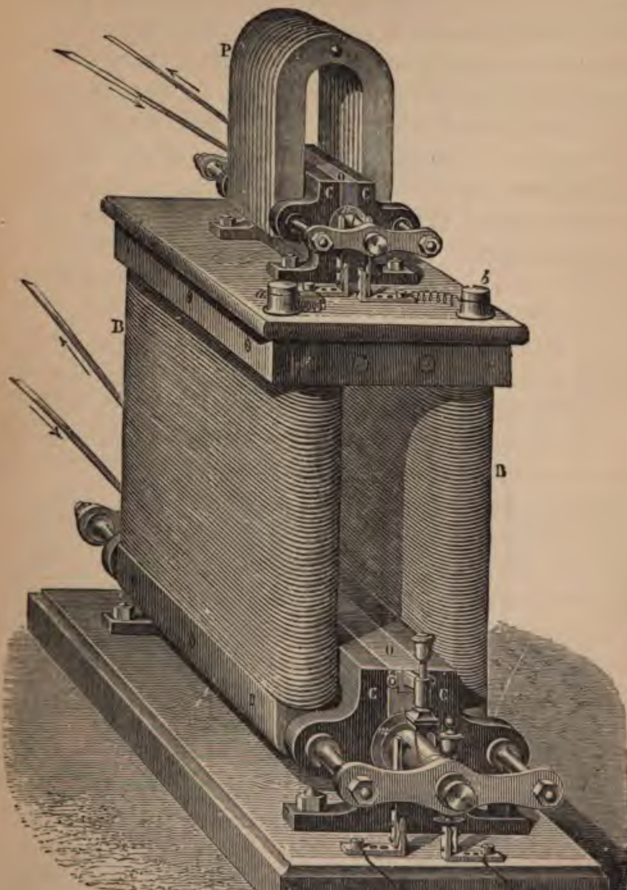


FIG. 29.

Siemens armature revolves, being driven by the belt at the back. The induced currents are all made to flow in one direction by the commutator (see Fig. 28). On the axle of the armature beyond the coil are fixed two strips of copper insulated from each other, and having the two ends of the wire attached to them. Two metallic springs connected with the terminals *a* and *b* press against these copper strips as they revolve. Thus although the current in the coil is reversed as it passes the pole, its connection with the terminals is also reversed at the same moment, the copper strip which was in contact with the spring of *a* now coming against that of *b*, and *vice versâ*, so that the current from *a* and *b* is always in the same direction. This is now led round the coils of the large electro-magnets B B, between the pole-pieces of which the second larger Siemens armature revolves, giving a still stronger current.

What Wilde did was to show that the current from a magneto-electric machine could be used to excite the poles of a still larger electro-magnetic machine, and enable a more powerful current to be generated from it. But then why not use the current which the machine itself generates to excite its own electro-magnets? This idea came simultaneously to Siemens and Wheatstone in 1867, and it was carried out by Ladd. Few specimens of iron are so pure as entirely to lose their magnetism, when they have once been magnetised. The small residuum of it suffices, when the machine begins to turn, to generate a feeble current, which after a few rapid revolutions increases the magnetism, until in a very short time it reaches the limit of its power. Thus was the problem solved and electricity generated by mechanical means with the aid of a minimum of permanent magnetic force. All machines in which this is the case are

called dynamo-electric machines, or briefly, dynamos, to indicate that they generate electricity in this way.

Ladd's machine is represented in Fig. 30. It has a pair of electro-magnets with pole-pieces, and a revolving Siemens

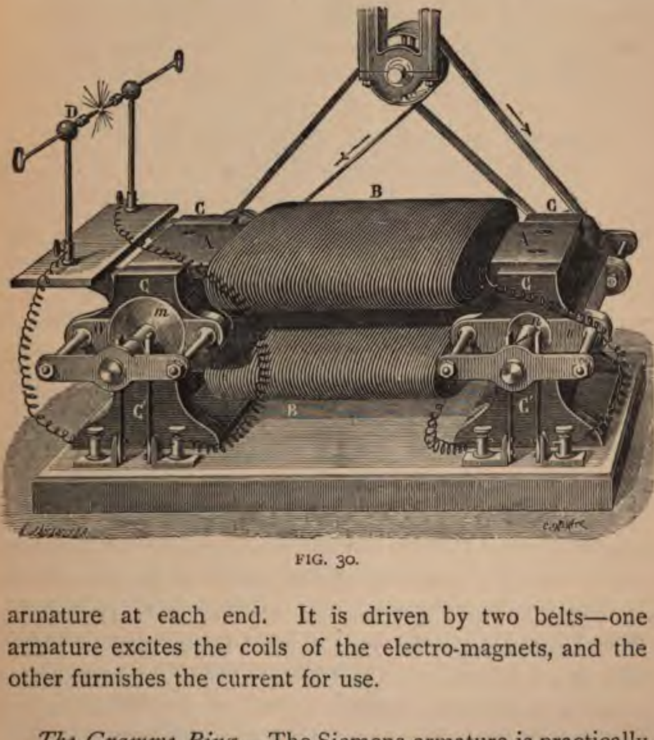


FIG. 30.

armature at each end. It is driven by two belts—one armature excites the coils of the electro-magnets, and the other furnishes the current for use.

The Gramme Ring.—The Siemens armature is practically obsolete, because it heats too rapidly and has to revolve at too great a speed. But it was through it that the possibility of the dynamo was demonstrated. In 1864 Pacinotti

discovered another principle which was lost sight of until, in 1880, Gramme brought out his armature. This consists of an iron ring wound round with insulated wire, and revolving in its own plane between two magnetic poles as in the diagram Fig 31. The coils are all permanently connected

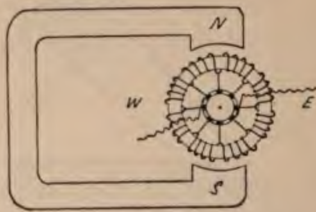


FIG. 31.

together so as to form a ring-shaped spiral. On the axis at one end of the armature are fixed as many copper bars as there are coils. These bars are insulated from each other, and a wire leads from each to the corresponding coil. Metallic brushes press against the bars, and draw off the current from each coil as it passes.

The student may be disposed to ask how it is that in a closed circuit a current can be developed which does not simply circulate round it, but can be led off to the outside without breaking the continuity of the ring? It may be replied that in the rheochord we have an analogous instance of a closed circuit from which we can lead off a current to the outside, though not the whole current of the battery. But the true answer is that in the Gramme armature there are two currents instead of one. For the sake of clearness the upper part of the ring may be called the north, and the lower part the south. Then, from the east, two currents will

start—one by way of the north through all the coils on that side, and the other by way of the south, meeting the first current in the west. Each coil contributes something to the electro-motive force, just as if it were a battery cell, but with this difference,—the direction of the current changes with the direction of the movement. As long as the coil is passing from west to east the current travels one way. Directly it begins to return from east to west the current is reversed.

Thus the two halves of the ring might be represented by a set of cells in series from west through north to east, joined in parallel with another set from west through south to east. Manifestly a wire connecting the east and west would carry all the current.

The essential difference between the action of Clarke's machine and the Gramme ring is this. In Clarke's machine the reversal of the current takes place as the coils pass the N and S poles. This is easy to understand from Faraday's experiments, which show that while a coil approaches a pole an inverse current is induced in it, and a direct current while it recedes.

But in the Gramme ring and in the Siemens armature, the reversal takes place when the coils are half-way between the two poles, and some difficulty is often felt with regard to the apparent anomaly.

The explanation is quite simple. In Clarke's machine as in Faraday's experiment, the *same face of the coil* is presented to the pole while it approaches and while it recedes.

In the Gramme ring and in the Siemens armature, the coils are continually turning over and over.

In order fully to explain the action, we must return to the conception of the lines of force. If we could concen-

trate all the magnetism in a single point, each pole might be compared to a candle radiating light. A half-crown held one metre off would intercept a certain quantity of the light. A threepenny piece at half a metre would receive rather more, for its shadow would be a little bigger. The half-crown moved up to half a metre would intercept four times as much as before, for its shadow would be twice as long and twice as broad. And in moving up, its circumference would cut through three times as many fresh rays as it had already enclosed.

So with a magnet of the same size. At half a metre it would receive four times as many lines of force as it did at one metre, and would therefore be attracted four times as strongly. A smaller magnet nearer to the pole might be attracted more powerfully than a larger one at a greater distance, if it cast a larger shadow, *i.e.*, intercepted more lines of force. Now a coil of wire acts like a magnet as long as there is a current flowing through it. But if there is no current, it behaves as a magnet only while in motion. That is to say, as long as it remains still and encloses the same number of lines of force (equivalent to casting the same shadow), it is neither attracted nor repelled; but directly it begins to cut the lines of force (change the size of its shadow) it becomes a magnet, and a current circulates round it. If it is approaching a N pole, the face of the coil next the magnet acquires the same polarity, so that the motion is resisted. If it is receding, it acquires the opposite polarity, and therefore still resists the motion. In other words, the current generated by the motion of a coil in a magnetic field tends to prevent its moving into a position of greater or less intensity (tends to keep the shadow of the same size). But we can alter the size of the shadow with-

out changing the distance, namely, by turning the ring edgeways. In doing so, the circumference will cut through all those rays or lines of force which it had enclosed, and the result will be the same as if the ring were removed to a very great distance.

This is what happens to each coil of the Gramme ring as it passes from W to N. At W it is wide open to all the lines of force reaching across from N to S. At N it is closed up. Proceeding from N to E, it opens out again and begins to cast a bigger shadow and enclose more lines. But the lines now thread through the ring from the opposite side, just as when the coin is turned over and the light strikes on the reverse. But here the analogy breaks down, because the shadow is the same in either case. We cannot have a candle radiating darkness as we have a south pole and a north pole to a magnet. Bearing in mind this difference, we find that as the coil opens out and encloses fresh lines of force in travelling from N to E, the current generated will be in the same direction as when it was closing up between W and N, because the lines strike on the other face of it.

But directly it passes E and begins to close up again the current is reversed, because the same face of the coil is still presented towards the north, and the number of lines enclosed is diminishing. And the flow continues reversed until the coil reaches the westerly position, since it turns over again in passing the south pole.

Hitherto we have dealt with the lines of force as though they proceeded from a single point at the end of the magnet, and have compared them with rays of light. In Chapter II. we saw that the lines of force are not straight, but reach in curves from one pole to another. We must modify our conception to make the analogy complete.

Suppose a bar of iron made red-hot at one end and ice-cold at the other, and suppose we place a delicate thermo-pile, capable of measuring the radiant heat, opposite a point ten cms. from the hot end, and gradually bring it nearer. The amount of heat indicated by it will *not* vary inversely as the square of its distance from that point, *unless it can be shielded from the influence of all the rest*, since it approaches the still hotter parts, as well as those that are colder, not in a direct line, but at an angle. The total heat received will be the sum of the rays from each point intercepted by the thermopile—the cold parts tending to neutralise the effect of the heat rays.

So it is that the lines of force about a magnet, which represent the strength of the magnetic field, are not straight, although induction, whether electric or magnetic, acts along straight lines just as light does.

For a line of force must be taken to mean the line along which the intensity of the field changes most rapidly from one pole to the other. This is most beautifully shown in an experiment recently brought forward by the Rev. F. J. Smith. A bar-magnet is fixed horizontally in a vessel containing a liquid, so that it may lie level with the surface. A magnetised needle thrust into a cork is made to float vertically in the liquid with its N pole upwards. On bringing this close to the N pole of the bar-magnet, it is repelled, and travels, first outwards, and then round by the curve of the line of force in which it happens to be, to the other pole, moving rapidly at first, then slowly, and finally quickly, to its position of rest. By attaching a mirror to the floating magnet, it is possible to photograph the course of these lines.

A simple apparatus, for illustrating the action of the

Gramme ring, was devised also by the Rev. F. J. Smith, and is shown in Fig. 32.

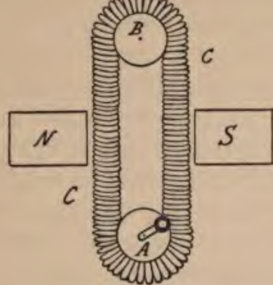


FIG. 32.

A and B are grooved brass pulleys fixed to a board, A being furnished with a handle. C is a spiral of hard brass wire with the ends soldered together. N and S are the poles of a powerful electro-magnet. On turning A by the handle, the wire coil is made to pass the poles, and if A and B are connected with a galvanometer, the needle will be deflected as long as the motion continues. Each loop of the wire, as it approaches N, will have a current generated in it. If, when it has reached the pole, the motion were reversed, the current would also be reversed. But as it passes N with a continuous forward movement, the opposite face of the loop is presented to the pole, and thus, although it is receding, the direction of the induced current is unaltered. But on reaching the pulley it turns over and comes back again through the same lines of force. Accordingly, the current is reversed at this point.

Yet another way of considering the Gramme ring is to

conceive the copper coils stationary, and the field magnets with the brushes revolving round them. The induction of the field magnets on the ring of iron forming the core will produce in it a pair of poles travelling round and round and threading through the coils always in the same direction—the one pushing a wave of current before it, and the other dragging a similar wave after it. These waves will be caught up by the brushes which follow each pole, and will be thrown into the external circuit. The way in which the presence of the iron core affects the magnetic field may be shown by fixing a soft iron ring between the poles of a horse-shoe magnet so as not to touch them, and then laying a sheet of paper strewn with iron filings over the whole and gently tapping it.

The lines of force will be found to reach across from one pole to the ring, along the sides of which they travel to the other pole.

There are very few inside the circle, and those that pass outside it are tangent to the ring at the E and W points, so that the greatest numbers are cut by the coils as they pass the poles.

There is a difference between the Siemens armature and the Gramme ring which it is important to notice. The axis of revolution of the Siemens armature is a diameter of the coil. But the coils of the Gramme ring revolve about a point outside their circumference. Not only therefore do they turn over in the magnetic field, but they travel bodily in a circular path within it. Now as each portion of the wire outside the ring necessarily leads in the opposite direction to the succeeding portion inside the ring, and as both are brought near the same pole, it follows that the effect of the one must be partly neutralised by the

opposite current due to the other. Were it not for the core, the total effect of the Gramme ring would simply be the difference between the number of lines cut through by a point on the inside and a point on the outside of the ring. But the iron core leads the lines round to the opposite pole, so that the inside half of the coil does not have to cut them. But still, though it does no harm it remains as so much idle wire. To obviate this disadvantage the *drum* armature was devised by Von Hefner Alteneck. The ring-shaped core is replaced by a solid cylinder, round which the wire is wound lengthways, much as string is wound on a ball—each turn, or else each group of turns, being soldered to the corresponding bar of the commutator. Thus the shape of the coils is the same as in the Siemens armature, but instead of being all parallel, they radiate as in the Gramme ring, and therefore give a steadier current. The Siemens (Alteneck) and Edison machines are of this type.

The Pacinotti, Gramme, Brush, Gulcher, and Burgin machines have "*ring*" armatures. The Gulcher machine is multipolar, *i.e.*, has four magnets instead of two, acting on the sides of the ring instead of its circumference. The Brush machine is what is called "open coil," that is to say, the segments of the armature are not permanently connected together, but each is joined up to its own commutator bars, and is only put in circuit by the brushes when it comes into the position of greatest activity.

Another type is the "*pole*" armature, in which the coils are wound, as it were, round the spokes of a wheel.

"*Disc*" armatures are those in which the coils are arranged in a disc as in Gordon's and Ferranti's alternators. In Gordon's machine the armatures are stationary and the magnets revolve. In Ferranti's dynamo the armature

revolves, its peculiarity consisting in the fact that it is essentially a strip of copper bent zig-zag so as to resemble a cog-wheel. There are twice as many field magnets on each side of it as there are loops or "cogs" in the armature. This machine gives a high-tension alternate current.

The details of the modern dynamo belong rightly to electrical engineering, and can only be treated here sufficiently to explain the meaning of certain familiar terms.

The first dynamos were "*separately excited*" and so are most of the alternate current machines. That is to say, the current round the field magnets is maintained by a separate dynamo having nothing else to do.

"*Series*" machines came next. (Fig. 33.) In them the

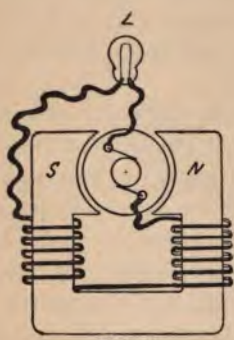


FIG. 33.

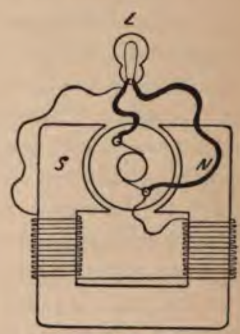


FIG. 34.

current is led from the armature round the field magnets, through the external circuit, back to the armature. In this case, if the resistance of the external circuit should increase, the current would be checked and the field magnets rendered less powerful, still further reducing the output. If the external circuit should be broken, the machine would

cease to act. On the other hand, as the external resistance diminishes, the current increases, and the heat generated appears in the machine with a risk of burning up the coils.

The "*shunt winding*" (Fig. 34) is intended to obviate this difficulty. Two sets of wires are led from the brushes—one to the external circuit and the other round the field magnets. Thus, when the external resistance is low most of the current passes that way and but little circulates round the magnets—keeping the field weak and the E.M.F. low.

But the more resistance there is in the external circuit, the more current passes through the magnet coils. Consequently the field becomes stronger and the current also, in proportion to the demand upon it.

In such a machine there is only a strong field when there is a large external resistance, *i.e.*, just the reverse of what would happen if it were series-wound. Consequently, to

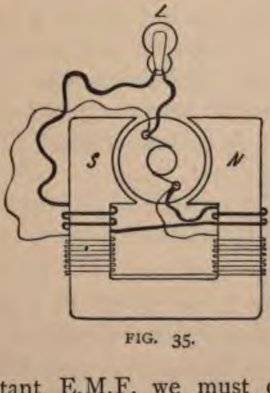


FIG. 35.

keep up a constant E.M.F. we must combine the two methods, as in Fig. 35 ("*compound wound*").

In addition to the shunt, which is of fine wire, a few turns of the thick wire of the external circuit are coiled round the magnets. These, when the resistance is low and the current large, serve to maintain the field. But when the resistance is large and the current small, the shunt coil with its many turns comes into action.

We now come to another point, namely, the position of the brushes. Each coil as it cuts through the lines of force becomes a magnet, having its poles at right angles to its diameter. In a dynamo the leading face of each coil has the same polarity as the field magnet which it is approaching, or—in the case of the Gramme ring, etc.—to which it is opening out so as to take in more lines of force. Now it may be easily shown with iron filings that the effect of presenting like poles together is to bend the lines of force away from each other. Consequently, as the armature revolves, the magnetic field is "*distorted*," and, as it were, driven round to a certain extent in the direction of rotation, so that the region of greatest activity is no longer opposite the middle of each pole, but a little way past it. Consequently also the neutral points, where the current is reversed, and where the brushes must be placed, are no longer east and west, but a little further onwards. This is called the "*lead*."

It is small if the strength of the field magnets is much greater than that of the armature.

Motors.—Nearly every electrical action is reversible. The revolution of a dynamo generates a current. The passage of a current through a dynamo causes it to revolve. We shall refer here to one or two points only in connection with dynamos used as motors.

The passage of a current causes the armature to revolve in the opposite direction to that which would generate the same current—for as it acts by attraction and repulsion it is evident that the leading face of each coil must have the opposite polarity to that of the field magnet which causes it to approach. The lines of force are distorted by it—but instead of repelling them, the armature pulls on them as it revolves. The brushes therefore must be shifted *backwards* instead of forwards to find the neutral point where there is no sparking.

Another curious question arises. Every motor is also a dynamo, and therefore in the act of revolving *generates a current opposite in direction to the current that causes it to move. This is called "counter electro-motive force."* Its existence may be shown by putting an ammeter (or galvanometer of low resistance) into the circuit. First let the motor be stopped, and measure the current. Then allow it to revolve. The current will immediately become less, being the difference between that of the driving dynamo, and that due to the *motor acting as a dynamo.* Consequently the twisting force, or "*torque*," on such a motor is greatest when it is nearly still, and it then takes the largest amount of current. Directly the load is taken off, the motor spins rapidly, and in so doing generates a counter E.M.F. which prevents so large a flow from the generator—the difference representing the amount consumed in performing the work.

To keep the speed constant under a variable load, different means of regulation have been devised, too complex to be considered here.

Motor Transformers are used in electric lighting. A

motor wound with fine wire can be driven by a small current of high potential brought to it from a distance by a comparatively small cable. The same shaft also carries a second armature, wound with short thick wires for quantity, acting as a dynamo and generating large currents of low E.M.F., either alternating or continuous according to the arrangement of the commutator. This is called a "step-down transformer." In the "step-up transformer" the motor part has the thick wire, and the dynamo part is wound for high tension.

Efficiency.—The student has already been introduced to the idea that all forms of energy are convertible one into another, according to a certain rate of exchange, and it is the business of the engineer to effect this conversion with as little loss as possible. For although the ratio of heat to work, and of work to electrical energy, is definite and constant, there is always something to be paid, as it were, by way of brokerage, for changing one into the other. The amount of this loss depends upon the system used, and the ratio of power consumed to power available for use is called the "efficiency" of the machine.

Electrical science owes a great deal to the labours of the engineer. It matters little in our laboratories whether the trifling quantity of electricity we use costs sixpence or a shilling, but it makes all the difference to a scheme for the electric lighting of a town. Were it not for this powerful stimulus to research, much that belongs to pure theory would have remained unknown.

Electrical apparatus, as at present made, gives back a larger percentage of the power absorbed than almost any other kind of machine. In a series of trials by Mr.

Crompton, of dynamos by various makers driven by Willans' engines, the efficiency of the dynamos alone varied from 90·7 % to 95·8 %—that is to say, for every hundred units actually generated in the machine, 95·8 units were sent into the mains, only 4·2 units being lost.

Besides this, however, there are the losses in the engine due to friction, etc., so that the total commercial efficiency of engine and dynamo combined was in the two cases 81 % and 86·2 % respectively. It is no uncommon thing for a 5 H.P. motor to have an efficiency of 85 %—that is to say, 4,388 watts, or about 5·8 H.P., would be required to drive it, but the consumer would only get 3,730 watts, *i.e.*, 5 H.P., from it.

In transmitting power to a distance by electricity, there is a further loss in the mains. In the description of the rheochord, it was shown how the difference of potential decreases regularly along a conductor in proportion to its resistance, so that in order to maintain a high E.M.F. at the ends of a long pair of cables, a still higher E.M.F. must be kept up at the generating station. The ratio of these two quantities is the *efficiency of distribution*, and the difference between them is the "loss in the mains," which can of course be easily given in the form of a percentage.

When accumulators are used there is a further loss in them, for it is impossible to get out of a storage cell quite as much as is put into it. At Kensington, Mr. Crompton found that the total loss of energy from this cause need never exceed 20 per cent. of the total amount taken out of the storage cells at the time when they are being discharged by themselves, *i.e.*, when no moving plant is running, and that the total loss entailed by the use of accumulators was not more than 4 per cent. of the total current generated.

But the advantages of being able to store electrical energy during periods of little demand may be judged from the fact that in practice it requires an average of at least 8 lbs. of coal to generate a unit of current without employing accumulators, against 4·5 lbs. when they are used. This is almost entirely due to the fact that an engine works most economically when the "*load factor*," or proportion of the work actually done to the work it is capable of doing, is as high as possible.

In order to calculate the loss in any conductor, we may proceed in various ways according to the data available.

Thus, if we know the entire resistance of the circuit, then each separate part lowers the E.M.F. in proportion to its resistance.

Or if the amount of current, and the difference of potential between the two ends of the wire (*i.e.*, the fall of pressure due to it) are given, then the product of the amperes by the volts gives the number of watts lost.

Or it may be necessary to calculate the loss from a given current through a conductor of known resistance. In this case multiply the *square* of the current by the resistance of the mains, and the result will be expressed in watts. Suppose, for example, in a small installation we have to supply 20 lamps with ·5 ampere each at 100 volts, and that the resistance of the main is ·5 ohm. What must be the pressure at the dynamo, supposing all the lamps to be tolerably near each other?

Putting the lamps in parallel, the current required will be $20 \times \cdot 5$ ampere $=$ 10 amperes. The loss in the main will be 10 amperes $\times$ 10 amperes $\times \cdot 5$ ohm $=$ 50 watts or volt amperes resisted. Since the current is 10 amperes, we have

$$\frac{50 \text{ volt-amperes}}{10 \text{ amperes.}} = 5 \text{ volts.}$$

The full of potential in the mains will therefore be 5 volts, and the pressure at the dynamo terminals must be kept at 105 volts to give the requisite current.

But if we had to place the lamps at equal intervals all along the line, it is evident that the nearest would get more current and the farthest less than it should have. It would be necessary, therefore, either to put in local resistances on each branch circuit, which would entail loss, or to run an extra wire to the far end, or in some way to equalise the pressure. Moreover, the turning off of several lights near together might seriously disturb the flow, and send too strong a current to one portion of the system. For this reason pilot wires are connected with the mains at different points, so that the difference of potential at those parts may be ascertained by the engineer.

The details of such a system of electric mains must be sought in works on engineering.

CHAPTER XIII.

POWERFUL CURRENTS.

We have now to consider briefly the relation between electrical currents, heat, work, and chemical change. Our dynamos are driven by steam generated by the heat evolved during the combination of carbon with oxygen—that is to say, the combustion of coal in a furnace. A ton of coal while burning gives out a definite quantity of heat, namely sufficient to raise the temperature 8,000 times its weight of water from 0° C. to 1° C., or to bring 80 tons of ice-cold water up to boiling point. As it requires in round numbers 540 units of heat to change boiling water into steam, a ton of coal in burning would evolve sufficient to boil away $\frac{8000}{540}$ $=14{\cdot}8$ tons of water if already heated to 100° C. Not only is a definite quantity of heat evolved, but the work capable of being done by it cannot exceed a certain amount. Everyone knows that heat can be generated by friction, and in 1842, Mayer stated that there is a connection between the power consumed in friction and the heat evolved.

It is usual to measure work done in terms of weight lifted to a height. Thus the old English unit is the foot-pound, the continental unit the kilogramme-metre, and the scientific or C.G.S. unit is the *erg*. The work done in

raising one gramme weight through a height of one centimetre is 981 ergs. (See Appendix.)

In order to determine how much heat could be evolved by spending a definite amount of work in friction, Joule, who was experimenting in Manchester quite independently of Mayer, arranged an apparatus like an egg-whisk worked by a cord and a weight, which could be drawn up to a height of 63 feet, and made to stir up a measured quantity of water as it descended. The friction of the liquid caused it to become sensibly warmer, and it was found that it required 772 foot-pounds of work to raise the temperature of a pound of water 1° Fahrenheit. Or in French measure, 1 kilogramme falling through 424 metres would raise the temperature of 1 kilogramme of water 1° Centigrade. On the C.G.S. system the "mechanical equivalent of heat" is 42 million ergs. This is called the *Joule*. What then is the *mechanical equivalent of electricity* and the *heat equivalent of electricity?* If such equivalents exist, do they agree among themselves?

We must first define the word power as distinct from work. It is not enough to know that a given machine can raise a certain number of kilogrammes so many metres unless we are also told how long it takes to do it. Two men may perform the same work, but the one who has most power can get through it quickest. Power is the rate of doing work. An engine of one "horse-power" (1 H.P.) can perform the work of raising 33,000 lbs. through one foot, or 1 lb. through 33,000 feet, in one minute. An engine of 2 H.P. would do it in 30 seconds. This unit of power is due to James Watt, who wanted to be able to tell his customers how many horses one of his steam-engines could replace. He found by experiment that a horse could

do 22,000 foot-pounds of work per minute, and made his "unit of power" half as much again, knowing that it would more effectually advertise his machines to under-state their capabilities.

We next enquire how much electricity can be generated by 1 H.P. in one hour. The Board of Trade unit, by which electricity is sold, is equivalent to 1000 amperes flowing under a pressure of one volt for one hour. This would be a current of 10 amperes if the pressure were 100 volts. It is usually defined as 1000 volt-amperes or *watts.*

1 H.P. would generate 746 watts, if used to the best advantage. Therefore, 1 Board of Trade unit = 1·34 H.P. for an hour. This may be called the practical mechanical equivalent of electricity. A watt is equal to about 44·2 foot-pounds, or 6·116 kilogramme-metres per minute.

It remains to discuss the heat equivalent of electricity.

When zinc is immersed in dilute sulphuric acid the solution becomes warm as the zinc dissolves. Is the quantity of heat generated proportional to the weight of metal which has entered into combination? And would the same amount of zinc dissolved in a galvanic cell evolve the same number of heat units? This problem was investigated by Favre, who enclosed a small battery in a calorimeter, and showed that it made no difference whether the zinc simply dissolved at random, or was arranged so as to generate a current. The solution of 33 grammes of zinc in dilute sulphuric acid, caused the evolution of 18,682 heat units, *i.e.*, enough to raise the temperature of 18,682 grammes of water from 0° C. to 1° C. Now comes another question. The passage of a current through a wire warms it—is this additional, or is it a part, and if so, what proportion is it of

the heat due to the chemical reaction? The experiments of Favre furnish the answer. He used two calorimeters, putting the battery in one, and the wire through which the current circulated in the other. The same total quantity of heat was given off, but it was divided into two portions according to the ratio between the resistance of the battery in the one calorimeter, and of the circuit wire in the other. Here we have an illustration of the striking difference between ordinary combustion, and that form of combustion which goes on in a galvanic battery. In the one case the heat is evolved at the place where the chemical union occurs, *viz.*, in the furnace. In the other case the heat is evolved where the electrical current is resisted, If we have no wire at all, but simply let the zinc touch the copper in the acid, the cell grows hot, and so it does if the circuit consists of a short thick wire. But if we use a long thin wire the cell keeps cool, and the wire becomes warm. For instance, suppose the resistance of the cell to be 1 ohm, and that of the wire 9 ohms, then the whole resistance of the circuit is 10 ohms, and for every 33 grammes of zinc dissolved, 18,682 heat units will be generated, 187 in the cell and 18,495 or thereabouts, being 9 times as much, in the wire.

Favre also tried the effect of causing the current to do work, namely in driving a small motor, the coils of which constituted the resistance. But in this case, on adding together the heat evolved in the circuit and in the cell, the total came to *less* than the calculated amount. Some of the energy was converted into work. In one experiment the little electrical engine performed 12,874 million ergs of work during the consumption of 33 grammes of zinc; and the total heat evolved by it and by the battery, was 18,374

units. Now 42 million ergs is the mechanical equivalent of one heat unit, so that the work done by the motor represented 306 units. Adding this to the heat actually evolved, we get $18,374 + 306 = 18,680$ heat units, which is very nearly the theoretical quantity corresponding to the 33 grammes of zinc dissolved. Thus we see that the heat evolved by the chemical action is distributed throughout the circuit in proportion to the resistance of its several parts, and that when a current is made to do work, for every 42 million ergs of work done, 1 unit, or as much heat as would raise the temperature of 1 gramme of water from 0° to 1° C., disappears.

It is found that *a current of one ampere flowing through a resistance of one ohm, develops in it* 0·24 *heat units per second.*

A heat unit is called also a calorie, and 0·24 of a calorie is sometimes used in calculation under the name of a *Joule*, so that

$$1 \text{ calorie} = 4{\cdot}2 \text{ Joules.}$$

The student must not confound the *amount* of heat generated in a particular portion of a circuit with the *rise of temperature* produced at that part. Suppose one piece of the wire is only half the diameter of the rest. Then the resistance of ten cms. of that portion will be *four times* that of an equal length of the thicker wire, and consequently its share of the heat evolved will be four times as great. But the weight of this piece is only one quarter that of the wire of twice the diameter, so that the rise of temperature in it, supposing none of the heat to be dissipated, would be *sixteen* times as great.

The rise of temperature is inversely proportional to the fourth power of the diameter of the wire. This is why the

fine carbon filament of an incandescent lamp can be made to glow brilliantly while the wires leading to it remain cool.

Joule found that the number of calorics, H, developed in a conductor is directly proportional to—

(1) Its resistance, R, in ohms;

(2) The square of the current, C^2, in amperes;

(3) The time, *t*, in seconds, during which the current flows;

(4) Multiplied by 0·24, the heat evolved by the passage of one ampere through one ohm for one second.

Thus: $H = C^2Rt \times 0{\cdot}24$, or $4{\cdot}2 \times H = C^2Rt$.

Different metals are differently heated by the passage of a current, and for two reasons, with one of which the student is already acquainted. The specific resistance of some substances is higher than that of others, and consequently in a conductor of the same dimensions, a greater number of calories would be generated. But each metal has also a different *capacity for heat.* That is to say, the same quantity of heat which would raise 1 gramme of water from 0° C. to 1° C. would raise rather more than $17\frac{1}{2}$ grammes of silver, or 30 grammes of platinum, or about $10\frac{1}{2}$ grammes of copper, from 0° C. to 1° C. Platinum would therefore be raised to a higher temperature than either of these other metals, under the same circumstances. The following experiment is taken from Silvanus Thompson's *Electricity and Magnetism.* Make a chain of alternate links of silver and platinum wire of the same size, and send a strong current through it. The specific resistance of platinum is about six times that of silver, and its capacity for heat not much more than half as great. The rise of temperature in the platinum links will be roughly twelve times that in the

silver, and they will become red hot while the silver links appear dark.

To sum up. By concentrating the resistance of a circuit in a few points, we can cause the heating effect of the current to be manifested at those points to so great an extent that the rest of the circuit remains practically cold. This is what is done in electric lighting. The high resistance is provided by the filament of the incandescent lamp, which must therefore be thin, incombustible, and very refractory. At first platinum was tried, but in spite of its high melting point was liable to be fused, and the more so because, like all metals, the hotter it gets the higher the resistance becomes. With carbon the reverse is the case, and moreover it does not melt at all, but on the other hand it burns away, even when in the form of graphite, if strongly heated. This difficulty was got over by enclosing it in a glass bulb exhausted of air. In order to make a strip of carbon fine enough, various vegetable substances are used which leave a tough ash when burnt. Thus Edison uses a thin strip of bamboo, and Maxim employs parchment paper —that is, paper which has been dipped in strong sulphuric acid—while the filament of the Swan lamp consists of a cotton thread parchmentised in the same way. In all cases, after bending the filament into the required shape it is carbonised by heat, and enclosed in a glass bulb, platinum wires being provided to convey the current through the glass to the carbon. Another difficulty had to be dealt with. Carbon absorbs a considerable quantity of any gas with which it may come in contact, and gives it out again when heated. To get rid of this and ensure a perfect vacuum, the lamps are exhausted a second time while in a state of incandescence, before they are finally sealed up.

Incandescent lamps are made of different resistances according to the use to which they are to be put. Some are adapted to work with portable batteries—such as from 2 to 4 accumulators. These require potentials of from 3 to 8 volts, and have short filaments of low resistance. Others again for lighting houses are adapted for currents at a pressure of 100 volts or thereabouts. For instance, a 16-candle Swan lamp, with a resistance of 158 ohms while hot, required ·62 ampere of current at a pressure of 98 volts, and twelve of these lamps could be driven by 1 H.P., that is to say, they required $62\frac{1}{8}$ watts each.

A 20-candle lamp took ·66 ampere at 100 volts, the resistance being 151·5 ohms, and the power required was 68 watts, *i.e.*, $\frac{1}{11}$th of a horse-power. The light emitted by a given lamp depends on the current sent through it. At first the filament is merely warmed—then it becomes red-hot and finally white-hot. At this point a comparatively small addition to the current yields a greatly increased brilliancy, but the "life" of the lamp is shortened, so that it becomes a problem whether it is more economical to risk the speedy rupture of the filament or to remain content with less light. But as regards the quantity of illumination obtainable *from a given current,* the greater the intensity the greater the economy. There is a widespread idea that no heat is given out by the electric light. This is not so. The heat emitted by even a 1-candle lamp is considerable, but the filament is so intensely hot and so fine that the proportion of heat to light is much less than in the case of an ordinary candle or gas flame, and if the bulb is broken, the fine thread of carbon is consumed by the oxygen of the air before it has time to set fire to anything.

In an electric light installation, therefore, heat is gener-

ated in enormous quantities in one place, and by means of electricity regenerated in small quantities at a number of separate places a long way off. Every kilogramme of coal burned evolves a definite quantity of heat, but the whole of this cannot as yet be transformed into its equivalent of current.

At Chelmsford, Mr. Crompton found that, for every Board of Trade unit generated, 8·88 lbs. of coal were consumed, and no less than 83 per cent. of the current from the dynamos was distributed to the customers. Thus, for each unit sold, 10·7 lbs. of coal were burned. But there are many circumstances tending to make the consumption much greater than the theoretical amount. The heat of combustion does not generate the current directly, but is used to make steam to drive the engines which turn the dynamos. Now both engines and dynamos work most economically when running at full speed—and this they cannot do continuously on account of the variable nature of the demand. A sudden fog in winter may require all the available power of the machinery, and just before the dinner-hour thousands of additional lamps are turned on for a short time. To meet this difficulty, storage batteries are used—much in the same way as gas companies employ gasometers.

It has been calculated that under the most favourable conditions as regards constancy of demand, using the best boilers, engines, and dynamos obtainable, a consumption of 2½ lbs. of coal should suffice to generate one unit of current. This limit has not yet been reached, an average of 7 lbs. per unit for a month during the best times of the year being quoted as extremely good.

Mr. Preece has made an interesting calculation, taking 8

lbs. per unit as a basis. One pound of coal would yield 4·5 cubic feet of gas, which, supposing it to be of average quality, and to be burnt in an ordinary burner, would give the light of 13·5 candles for one hour. The same quantity of coal would serve to generate a current capable of producing in an incandescent lamp the light of 42 candles. But if, with improved systems, the limit should be reached of obtaining a Board of Trade unit with 2½ lbs. of coal, then each pound of fuel would yield, with incandescent lamps, 130 candles, and with the arc lamp, 700 candles for one hour. Other authorities give figures less favourable to electricity. One unit is considered to be capable of feeding twenty 14-candle Swan lamps for one hour, and this is equivalent to the light given by 100 cubic feet of gas. As has been already said, the standard of comparison must depend very much on the degree to which it is considered advisable to work the lamps. On the lower estimate, 10 units, and, on the higher, 6 units, are considered to give the light of 1000 cubic feet of gas.

The principle of localising the heat generated by a current, by a suitable arrangement of the resistance of the circuit, may be applied in many ways. For instance, a coil imbedded in the bottom of a saucepan will serve to boil the water in it. In this case it is unnecessary to raise the temperature so high. Electric welding is another instance of its use. The two pieces of metal to be joined are held in massive copper jaws, so that only those portions which it is necessary to heat project beyond them. The two ends are then brought together, and a current of low intensity, but enormous quantity, is allowed to pass. The resistance of the copper jaws, which serve as conductors, being extremely small in proportion to that of the metal to be welded,

they remain cool, while in a few moments it is brought to a welding heat, and the parts pressed together like two sticks of hot sealing wax. Such joints require annealing, as the metal is sometimes rendered brittle, probably by the extreme suddenness of the change of temperature; but with proper precautions they are very strong. The perfection of the method may be judged by the fact that not only can thick bars of iron or steel be thus united, but a length of copper wire joined in 50 places has been submitted to the tests for conductivity required by the Post Office authorities, and passed without its being detected that there was anything unusual in the sample.

Before leaving this branch of the subject, it is necessary to describe the other form of electric lamp, namely the arc light. This differs from the incandescent lamp in having no conductor to convey the current, save the heated air and vapourised substance of the two poles. It was discovered in 1800 by Humphrey Davy that the momentary spark, observed when the wires of a battery are separated, is replaced, if the current is large and strong enough, by a flame or arc which is continuous as long as the ends are not too far apart. As the heat thus produced is so intense as to melt even platinum, metals cannot be employed to form the arc. Davy accordingly tried carbon, which is infusible. Ordinary charcoal is speedily burnt away, but graphite or gas carbon is only slowly consumed. At the present time the carbon rods are made of powdered coke or graphite, mixed with a tarry substance and strongly heated, thus making a coherent mass, which is then repeatedly soaked in tar or syrup and fired in a closed vessel until all the pores are filled up with solid carbon.

To start the light it is necessary that the carbons should

touch, as the currents employed are not of sufficient intensity to overcome the resistance of cold air. But directly they have touched they must be separated, otherwise the whole length of carbon would become red-hot and the rods would be welded together—not perfectly, as in the case of metals, but still sufficiently to transmit a large amount of current and emit great heat but very little light. They would, in fact, constitute a very wasteful form of incandescent lamp. On the other hand, if they are separated to too great a distance, the resistance of the "arc" of heated gases increase to such an extent that the current passing no longer evolves sufficient heat to volatilise the poles, and the light goes out. For this reason a lamp or "regulator" is employed. The Serrin lamp may be taken as the type of the older form. The carbons are attached to brass supports provided with toothed racks actuated by cog-wheels in such a way that on winding up a spring the two ends steadily approach each other until the machinery is stopped by their coming in contact. As in practice it is found that the positive pole wears away about twice as fast as the negative, the wheels are so arranged that the former moves with double the rapidity of the latter. Thus far we have described the machinery for bringing them together so as to start the current. In order to separate them and produce the arc, the lower carbon is attached to the armature of an electro-magnet, the coils of which form part of the circuit. The carbons are first adjusted and then drawn apart by hand, and when the current has been switched on, allowed to approach each other. Directly they touch, a spark passes, the armature is attracted, and the bottom carbon drawn sharply away from the other. Before the slow action of the spring can bring the two together again,

the train of wheels is locked by the same movement of the armature. The disintegrating action of the current burns away the carbons till the arc becomes so long, and its resistance so much greater, that the quantity of electricity which passes is no longer sufficient to hold down the armature, which accordingly rises, setting free the train of wheels, and thus allowing the carbons to approach until the diminished resistance of the arc, and consequently increased strength of the current, enables it to lock the escape wheel and stop them.

Another principle is that of the solenoid, which is used in a variety of lamps, notably those of Siemens, Brush, Lontin, and Crompton. It is shown in diagram in Fig. 36.

A and B are the two carbons, one of which is connected with a spindle-shaped iron rod C, attached to a plunger inside the two coils D and E, and guided by metal rollers F. D is part of the main circuit, and consists of a few turns of thick wire; but E forms a shunt, and is made of thinner wire with greater resistance and a larger number of turns. The current has therefore two paths—one by way of coil D to the roller F, and thence by the plunger to the carbons A and B, between which it forms the arc, and the other through the coil E without traversing the lamp. When the switch is turned on, the coil E comes first into action, drawing the plunger down till the carbons touch. But immediately the powerful current which flows through D overcomes all the attraction of E and draws the iron plunger C upwards, separating the carbons. In so doing it lengthens the arc, increases the resistance, diminishes its own share of the current, and increases that of the coil E, so that a point is reached at which the power of the one equals that of the other, and the core C is balanced between the two.

Provision is made for adjusting the carbons as they waste away, in much the same way as in the lamp already described.

The Jablochkoff electric candle needs no such adjustment. It consists of two carbons side by side, separated by a strip of plaster-of-Paris. The arc is started by laying

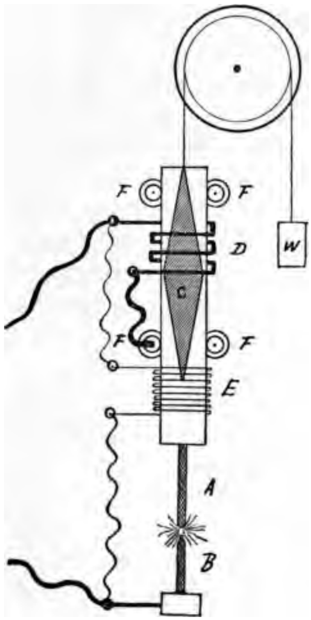


FIG. 36.

a small piece of carbon across the poles at the top, and the heat burns away the gypsum as well as the carbon. But in order to obviate the difficulty of the positive pole being con-

sumed more rapidly than the negative, it is necessary with these candles to use alternate currents.

It is very instructive to fix two long carbons upright side by side about 5 mms. apart, and to start the arc between them by touching both at once with the end of another carbon. They will burn steadily though unequally if lighted at the top, but if lighted near the bottom *the arc will travel steadily upwards till it reaches the extreme ends*, thus illustrating the fact that succeeding portions of the same current repel each other.

The resistance of the arc varies, according to circumstances, from ·5 ohms to 100 ohms. The E.M.F. may be from 40 volts upwards. The arc may be shown for a short time with the current from a few bichromate cells, if small carbons soaked in fused caustic potash are employed, but it is of course of very moderate intensity.

The size of the carbons is a matter of some importance. If they are too large, the light is steady but dull. If they are too small, it "flames" strongly, and the carbons soon burn away.

For currents of 10 amperes they may be about 11 mms. in diameter; while for 15 amperes, 12 mms.; for 25 amperes, 15 mms.; and for more than 40 amperes, 20 mms., are suitable sizes.

With a current of 18 amperes at 69 volts, a pair of carbons 18 mms. in diameter gave a light of 4,400 candles.

To prevent more current flowing than the wires can safely bear, a "*cut-out*" is usually inserted in the circuit. Cut-outs are of two kinds—fusible and magnetic. In the first, advantage is taken of the fact that a current generates heat in its passage. They consist of a short piece of tin or other fusible wire of such diameter as to melt when the flow of

electricity exceeds the desired amount. The rule usually enforced by fire offices is that no copper wire is to carry more than 1000 amperes per square inch of section. Thus a No. 20 S.W.G. wire must not carry more than 1 ampere. Its resistance would be about 24 ohms per 1000 yards, so that the highest *safe* fall of potential would be at the rate of about $2\frac{1}{2}$ volts per 100 yards. If used to carry ·416 amperes, the loss of pressure would be about 1 volt per 100 yards. No. 14 S.W.G. would carry 5 amperes, while No. 8 S.W.G. would be safe with 20 amperes. But for large currents it is usual to employ stranded cables; *e.g.*, No. 3/22 (= 3 wires of No. 22 S.W.G.), carrying 1·884 amperes, might serve amply for two lights requiring ·6 amperes each, and leave a margin of 50 per cent. for safety, while 7/22 would take 4·396 amperes, or more than sufficient for six lights. The resistance of the latter would be about 5·7 ohms per 1000 yards, and the fall of potential, roughly, 25 volts in the same distance with the maximum safe current, and 10 volts when carrying 1·761 amperes. This mode of expression is usual among electrical engineers. It is a simple application of Ohm's law.

The Phœnix Fire Office rules, which are usually followed, require that every conductor should be capable of carrying safely twice as much current as is needed by the lamps upon it, and that wherever a branch is led off from any conductor there should be inserted a short length of lead, tin, or other fusible metal of such section, length, and nature, that if the current passing through it exceeds the normal current by 50 per cent., it will fuse and disconnect the branch.

Thus a tin wire ·0072 inch in diameter would fuse with 1 ampere, one of ·021 inch (about No. 24 S.W.G.) would

fuse with 5 amperes, while for 20 amperes the size would be ·0529 inch for tin, ·0595 inch for lead wire, and ·0343 inch (about No. 20 S.W.G.) for iron wire.

Just as a ball-cock is used to shut off the supply of water when the cistern is full, so magnetic cut-outs are employed to disconnect a dynamo from a set of storage cells directly they are charged. The principle is much like that of Pohl's commutator. The current passes round the coils of a magnet, and whenever it becomes sufficiently weakened by the back E.M.F. of the accumulator, allows the bridge of the commutator to fall over, and in so doing breaks the circuit.

For measuring large currents special instruments are employed. The *electro-dynamometer* is essentially a galvanometer in which the needle is replaced by a swinging coil like that shown in Fig. 23, but suspended by two threads (see the Quadrant Electrometer, p. 124). This instrument is capable of measuring alternating currents, for since the stationary and the swinging coil are both traversed by the same current, it is the *mode in which they are connected*, and not the direction of the current, that determines whether they are attracted together or repelled. Accordingly the deflections of a dynamometer index are all one way, and show the strength but *not the direction* of a current. There are numerous forms of ammeters (ampere-meters) and voltmeters in use for commercial purposes. Some of them are *zero-instruments, i.e.*, the strength of the current is measured by the number of turns given to a screw, etc., to bring the index back to zero. Others are essentially galvanometers with some device for shielding them from the disturbing action of magnetic field.

The magnifying-spring ammeters and voltmeters of

Professor Ayrton are frequently met with. A thin iron tube is suspended by a spring so as to hang a little way inside a hollow coil through which the current passes. This coil becomes magnetic, and sucks the iron tube into itself with a force proportionate to the strength of the current. The spring may be easily imitated by curling a strip of paper with a knife, and twisting it into a spill. A very slight change in the length of the spill necessitates a good deal of twisting or untwisting. So with these springs—a very small pull on the iron tube attached to them causes the free end to revolve through a considerable angle. Thus the movement is transmitted to an index, and much magnified.

Volt-meters, as the name implies, serve to measure differences of potential. Cardew's volt-meter does so by showing the expansion in length of a fine wire through which the current passes. For the passage of the current raises the temperature of the wire, until the radiation of heat from it to the surrounding objects is as rapid as the generation of heat within it, and as this depends on the quantity of current passing, it is evident that the consequent expansion of the metal must be in some ascertainable relation to the E.M.F. This instrument can be used for alternate currents, but it absorbs a good deal of power, and cannot be used for small differences of potential.

The Watt-meter, which measures power (since the watt or volt-ampere is $\frac{1}{746}$ H.P.), is a variety of dynamometer. It has one fixed and one movable coil. One of these is of thick wire, and the other of thin wire in parallel with the first. Accordingly, the magnetic effect of the second varies directly with the pressure, and that of the first with the current, so that their mutual action is proportional to the

product of pressure by current, *i.e.* the volt-amperes or watts.

Electric meters, not only to indicate, but to record the number of units consumed, must be studied in larger works. Some of them are voltameters arranged as a shunt on the main. Edison uses zinc, and Wright employs copper. A certain fraction of the current is diverted through the voltameter and conveys the metal by electrolysis from one pole to another. By weighing the plates from time to time, the amount of current consumed can be calculated.

In another type of meter, a small motor is arranged to do work on a brake, *e.g.* to turn a fan in air, or in some liquid. These may be designed to measure either the quantity of current supplied or the power represented by it, taking the pressure into account. In many cases, only the former is done, and the E.M.F. is assumed to be constant.

The Aron meter is on an entirely different principle. Two clocks are connected with an index hand in such a way that one causes it to move backwards and the other forwards. As long, therefore, as they both go at the same rate, the hand keeps still. One clock has an ordinary pendulum, but the other has an iron bob swinging over an electro-magnet. Directly a current passes, this attracts the bob, assisting the action of gravitation and making it swing faster so as to gain on the other clock, and make the hand go round. It is obviously necessary that both pendulums should be of the same length, for if the recording bob should oscillate more slowly than the other, it might chance that the customer returning from his holiday would find he had something to receive from the company—and *vice versâ* if it went too fast.

CHAPTER XIV.

SOME OTHER ELECTRICAL PHENOMENA.

THIS chapter deals with certain electric phenomena of great theoretical interest, but as yet of minor practical importance.

In 1821, Seebeck discovered that if two dissimilar metals are soldered together, and their free ends connected with a galvanometer, the needle will be deflected—in one direction if the junction is heated, and in the other if it is cooled. Currents thus produced are called *thermo-electric currents*, and the various forms of apparatus constructed on this principle are known as *thermo-piles*. Such a junction acts like a battery of very feeble E.M.F., but the current though extremely weak is of large quantity, because as the circuit is entirely composed of metals, the resistance is low.

The student may best gain an idea of the laws of the phenomenon by soldering a couple of stout copper wires, say thirty cms. long, to the two ends of a similar sized piece of German silver wire, and connecting them with a tangent galvanometer of low resistance. Tracing the circuit round, starting from the middle of the German silver, we have: German silver to copper wire, copper wire to copper coil round the galvanometer, copper coil to copper wire,

copper wire to German silver. There are therefore only two dissimilar junctions in the entire circuit. As long as these are both at the same time temperature whether hot or cold, there will be no deflection of the needle, but if we heat one or cool the other, a difference of potential will be indicated.

The E.M.F. of this current for any given pair of metals is, within wide limits, proportional to the difference of temperature between the junctions, and just as in a battery the electro-motive force depends on the particular elements involved in the chemical reaction, so in a thermo-pile each pair of metals produces for the same difference of temperature a current of a certain strength.

The following list is given in Silvanus Thompson's Electricity and Magnetism.

THERMO-ELECTRIC SERIES OF METALS.

Bismuth	+ 89 to 97	microvolts.
German Silver	+ 11·75	"
Lead	0	"
Platinum	— 0·9	"
Zinc	— 3·7	"
Copper	— 3·8	"
Iron	— 17·5	"
Antimony	— 22·6 to 26·4	"

That is to say, a copper-German-silver couple gives a difference of potential of $11·75 + 3·8 = 15·55$ microvolts for every difference of $1°$ C. between its two junctions, but a copper-iron couple would only give 13·7 microvolts. Manifestly, bismuth and antimony would be the most powerful pair, but the student will find it more convenient

to work with the cheaper couple composed of German silver and iron. Heat a piece of glass tube over a large bat's wing burner till some five or six cms. of it become soft, and then draw it out into lengths of fine tubing only just large enough to take the thin iron wire used for decorating purposes. Provide also a number of tubes of larger size drawn small at one end, but not sealed. Cut off some lengths of German

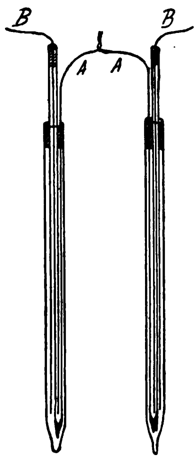


FIG. 37.

silver wire and of iron wire (about thirty cms.), and tin them at each end. Next, fix two of the wires side by side, separated by the thickness of a card, in a hand vice, and join them with a drop of solder at one end. Clean off the soldering fluid by boiling first in soda and then in water. Then push the iron wire through one of the fine glass tubes, which must be slipped down to the junction. The whole is

then to be inserted in one of the pointed tubes. It remains to secure the wires in place. This is done by immersing the large end of the tube in melted sealing-wax, and sucking a little of it up with the aid of a rubber tube slipped over the pointed end. Finally, seal up the points in a flame as close as possible to the end of the wires, and solder these "thermo-electric junctions" together in pairs by the *iron wires.*

Fig. 37 shows the appearance when completed. A A are the iron wires, and B B the German silver.

The E.M.F. of the couple is 11·75 + 17·5 = 29·25 microvolts for every degree Centigrade. Merely to bring the hand nearer to one of them will produce a strong deflection of the galvanometer, and if a sensitive instrument is used a difference of $\frac{1}{300}$th of a degree may be easily detected. Such couples may be joined in series exactly like the cells of a battery, taking care that all the odd numbers form one group, and the even numbers the other. In that case the total E.M.F. is the sum of the separate electro-motive forces of the various junctions. Thermo-electric batteries capable of giving strong currents have been devised, but they are costly both in manufacture and in use, and from some cause not perfectly understood, deteriorate after a time.

The principle is most useful for determining differences of temperature between two bodies, one of which is not readily accessible, or for measuring radiant heat.

If a current from some other source is sent through a thermo-pile, it cools all those junctions which if heated would give a current in the same direction, and *vice versâ.* This is called *Peltier's effect.* The quantity of heat evolved is *proportional to the current*, and *if the current is reversed cold is produced*, *i.e.* heat is absorbed. This distinguishes it from

the effect of *resistance*, which causes heat to be *evolved*, in proportion to the *square of the current*, *no matter which way it flows*.

Electro-optical Phenomena.—These are connected mainly with what is called *polarised light*, which can only be dealt with very briefly in this book. If a crystal of Iceland spar, which is a crystallised carbonate of calcium, is laid over a piece of white paper on which is a black dot, instead of one image, two dots will be seen side by side. Light passing through such a crystal (said to be doubly refracting) is separated into two portions, with opposite properties. It has been found possible to cut these crystals in such a way that only one of the two images is transmitted. They are then called Nicol's prisms. A Nicol's prism appears perfectly transparent like a piece of glass, of a rhomboid shape, longer than it is broad. If one is held in front of another so that the longer sides of the two are parallel, they are still transparent, but if turned so that one crosses the other at right angles, they are almost absolutely opaque, even to sunlight. This is because the light is so modified in passing through the first that all its vibrations are confined to one plane, and the second will only transmit vibrations in the same plane, and consequently stops them all when they fall upon it at right angles to that direction. If the Nicols are not quite at right angles, they allow a little light to pass, and the proportion that is transmitted increases as they are revolved, until perfect transparency is reached with the parallel position. It makes no difference whether the two prisms are close together or not, so by fixing them some distance apart other substances may be placed between, and their action,

as regards the "plane polarised light," transmitted by the first prism or polariser, may be studied. For example, cross the prisms so as to stop all light, and place between them a glass tank, or better, a tube about 20 cms. long with glass ends, filled with water, or brine, or dilute acid. No effect is produced. Pour out the water and substitute a strong solution of sugar. This will so affect the light from the polariser that some of it will pass the analyser or second prism; and to restore darkness, one of the Nicols must be turned round a little to the right or to the left, according to the particular kind of sugar used. It is just as though the syrup twisted the light in its passage so as to bring its vibrations into a different plane. Such liquids are said to possess right-handed or left-handed rotary power. The amount of the rotation varies with the concentration and the length of the tube, and also with the nature of the substance.

Pebbles, of which eye-glasses are made, possess this property, but glass does not. Faraday however, in 1845, discovered that a certain kind of glass, made principally of borate of lead, could so affect polarised light under certain circumstances. He placed a piece of it between the poles of a powerful electro-magnet so that he could look along the line joining them, through the first Nicol, the glass, and the second Nicol, at the flame of a candle. Having crossed the prisms so that no light would pass, he switched on the current and found that the flame immediately became visible, just as it would if syrup had been used instead of the magnet and the glass. On turning the analyser through a certain angle, the light was once more extinguished. The direction of the rotation is the same as that of the current round the coils, and Verdet discovered that its amount is

proportional to the strength of the magnetic force, and to the length of glass traversed by the light. Other substances possess the same power in various degrees, but in magnetic bodies, as opposed to those that are diamagnetic, like glass, the direction of the rotation is reversed.

There is another phenomenon of polarisation distinct from this, namely, that all substances which possess the power of double refraction, when placed in *certain positions* between crossed Nicols, enable light to pass. Crystals of nitre, or crystals of sugar as distinct from the solution, do so, but those of salt do not. In general, the property is only possessed by those bodies in which there is a stress of some kind greater in one direction than in the other, and it is only manifested when this stress occupies a certain position with regard to that of the Nicols. For instance, a film of india-rubber made by allowing the solution in naphtha to dry on a piece of glass, has no effect, but if it is peeled off and held on the stretch it at once enables the light to pass the analyser. When two surfaces oppositely charged are separated by a dielectric or insulating body, the electric attraction causes a stress between them, the existence of which may be proved by polarised light.

Two metal plates, 10 or 15 cms. broad, are supported firmly face to face, and fairly close together, in a tank with glass ends, so that the operator can look along the space between them. The tank is filled with carbon disulphide,[1] or turpentine, or certain oils and insulating liquids, and the two plates connected with the terminals of a Wimshurst machine. The whole is made to occupy the position of the tube of syrup in a polariscope, with the Nicols crossed. On

[1] This is so inflammable that the experiment should not be attempted without special precautions.

turning the machine, the two plates become oppositely charged, and the electric stress is made visible by the light passing most freely where it is strongest.

As a Nicol's prism is somewhat costly, it is well to note that light reflected from a piece of unsilvered glass is plane-polarised when it makes an angle of $35° 25'$ with the surface.

Cut two triangles of cardboard, with a base of 100 mms. and a perpendicular of 71 mms. Fix them inside a box with the lid off and a large hole cut in one end, and let a plate of glass rest on the sloping sides—securing it with gummed paper. Let a horizontal ray of light fall on the glass at this angle, and the reflected portion will be plane-polarised. A second piece of glass fixed in a similar manner may be held in the hand and used as an analyser. By placing the first box on its side, and making the incident ray parallel to the base of it, the polarised ray will be brought into a horizontal position, which is more convenient, as the second box need only be placed upright on the table in its path.

All the experiments referred to may, with a little care, be made with this arrangement.

Electrical Oscillations.—When a wave of electricity starts along a wire, it does not, as we might expect from the analogy of water in a pipe, begin to flow first in the centre of the metal, but along the surface or junction between the conductor and the non-conducting medium surrounding it. This state of things lasts an appreciable though a very short time. If therefore we use an alternating current of high frequency, we shall find that the phenomena are conditioned by the laws which govern

the *establishment* of a current rather than the *flow* of it. For instance, a bar of iron may be made so hot on the outside as to burn the hand, and yet feel cold the moment the current is stopped. Such currents never reach the middle of the conductor. Consequently, its resistance to them is much higher than to a steady flow, and has therefore received the name of "*impedance*."

A No. 2 wire, $2\frac{1}{2}$ metres long, bent into a circle, the true or "*ohmic*" resistance of which was ·004 ohm, was found by Dr. Lodge to have an impedance of 4 ohms at 250,000 oscillations per second, 43 ohms at 3 million, and 180 ohms at 12 million oscillations per second. A No. 40 wire of similar shape had an ohmic resistance of 2·6 ohms, and an impedance of 6 ohms for 250,000 oscillations per second, 78 ohms for 3 million, and 300 ohms for 12 million oscillations per second. These experiments suggest that it may be better for a lightning conductor to be flat so as to have as large a surface as possible for a given weight of metal.

Dr. Hertz of Carlsruhe has investigated the subject of electrical oscillations. Some of his experiments may be briefly described. A copper wire, 2 mms. in diameter and about 2 metres long, with a metal knob at each end, is bent into a rectangle, so that the knobs occupy the middle of one side and come nearly together.

A powerful induction coil is used as the source of electricity, the terminals being placed at such a distance apart that sparks pass freely. A flexible wire is attached to one of the terminals and the other end connected with the rectangle so as to slide along it like the rider of a rheochord. When it is placed near either of the knobs, sparks are seen to pass between them as well as between the terminals of

the induction coil, but if it is slipped round to the middle of the wire, the sparks cease. The oscillations produced by the discharge travel in both directions round the rectangle, and having an equal distance to go, reach the knobs in the same phase. Hence there is no difference of potential and no spark. But if now an insulated conductor is attached to one of the knobs, the sparks reappear, because the time required for it to become charged is increased. Placing a conductor of like capacity on the other knob restores the balance and prevents sparking.

The rectangle need not be connected with the coil if the circuit is arranged as in Fig. 38.

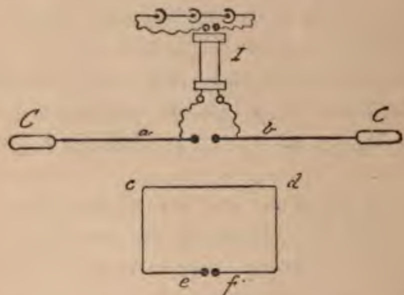


FIG. 38.

I is the induction coil, to the terminals of which are attached wires *a*, *b*, ending in conductors C C.

The rectangle *c*, *d*, *e*, *f* is not in any way connected with the rest of the circuit, and yet when the coil is in action sparking occurs between *e* and *f*, even when the rectangle is some distance away. To obtain the maximum effect, it is necessary to adjust the exciting circuit so as to produce the particular number of oscillations per second that the rect-

angle is capable of responding to. The apparatus may be compared to an organ pipe producing a certain note, and the rectangle to a resonator of the same pitch.

By means of these oscillating discharges it has been ascertained that electrical induction is propagated in space in much the same manner as light. It can be reflected and refracted. It is stopped by metals, but passes through non-conductors, such as dry wood, pitch, etc. A prism of pitch deflected the course of the radiation, and its index of refraction was found to be 1·7.

Interference phenomena, analogous to those of light, can be shown with these electric radiations.

The number of oscillations per second increases as the resonating circuit is made smaller, and it has been suggested that if we could operate with conductors as small as the molecules, we should get vibrations of the same frequency, the same wave length, and perhaps identical with the rays of light.

Pupin's Experiments.—A T-shaped glass tube, with a

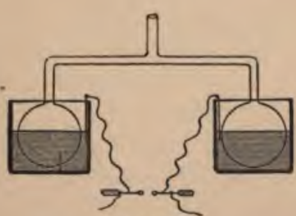


FIG. 39.

bulb at each end as in Fig. 39, is partially exhausted of air, and placed with the bulbs dipping into two beakers of

water connected respectively with the terminals of an induction coil. Each bulb forms a Leyden jar, the water in the beaker constituting the outer coating, the rarefied air serving to collect the charges on the inside and conduct them across by the tube. By immersing the bulbs to different depths, the "capacity" of the apparatus may be varied.

By this device a continuous oscillatory discharge may be kept up in an exhausted tube, without any metallic terminals, and it promises to be of great use in studying the spectra of gases.

The electrical flow has the appearance of a gliding film of luminous gas along the inner surface of the tube, spreading out round the bulbs, at the bottom of which it ends in violently agitated clouds of light.

In a similar experiment in which a small bulb at the centre of a large exhausted bulb formed the condenser, the discharges from the outer surface of the one to the inner surface of the other assumed the appearance of the corona seen round the sun during a total eclipse.

APPENDIX I.

ELECTRO-MOTIVE FORCE.

VOLTA found that the metals could be arranged in series so that any one of them would be negative to those preceding it, and positive to those that came after, on being placed in contact with them, without any acid or moisture. The following is the order in which he placed them: zinc, lead, tin, iron, copper, silver, gold. He also found that the difference of potential between any two is equal to the sum of the differences of potential between the intermediate metals. This list might be extended to other elements, but when they are immersed in different liquids, as in a battery, the order is not in all cases the same, and the resulting E.M.F. must be calculated otherwise, although Volta's law still holds for any one acid.

When a gramme of any given metal is dissolved in a given acid, a definite amount of heat is evolved. This is called its *heat of combination*. And as each unit of heat is equivalent to forty-two million ergs, it can obviously be expressed in terms of energy. The electricity evolved also represents the energy of the reaction, and it is measured by the product of its two factors, current and electro-motive force. The current produced is measured by the electro-

chemical equivalent of the metal (p. 142), and the electromotive force may be found as follows:—

Let E = the E.M.F.
H = the heat of combination.
J = the mechanical equivalent of heat.
Z = the electro-chemical equivalent of the metal.

Then $E = HJZ$.

In every galvanic battery some compound is formed at the expense of some other which is decomposed. The total available E.M.F. is the difference between the E.M.F. resulting from the one, and the E.M.F. necessary to effect the other. If all the chemical reactions of the cell, and the heat of combination in each case are known, then the resulting E.M.F. can be calculated. As there is usually some thermal effect connected with the solution of a salt in water, the degree of concentration of the liquids affects the E.M.F.

In the Daniell's cell the E.M.F. of the zinc dissolving in the acid is $+ 2{\cdot}359$ volts.

The E.M.F. required to decompose the copper sulphate is $1{\cdot}242$ volts. The difference, $2{\cdot}359 - 1{\cdot}242 = 1{\cdot}117$ volts, is the theoretical E.M.F. of the Daniell's cell.

APPENDIX II.

THE METRIC SYSTEM.

Length.

39·37079 inches = 1 m. or metre.
= 10 decimetres.
= 100 cms. or centimetres.
= 1000 mms. or millimetres.

1000 metres = 1 km. or kilometre.

Roughly 8 kilometres = 5 miles.
1 metre = $39\frac{3}{8}$ inches.
10 cms. = 4 inches.
25 mms. = 1 inch.

Fluid Measure.

1 litre = 1 cubic decimetre.
= 1000 cc. or cubic centimetres.

Roughly 100 litres = 22 gallons.
$28\frac{1}{3}$ cc. = 1 fluid ounce.
1 cc. = about 17 minims.

Weight.

1 gm. or gramme = 1 cubic centimetre of pure water at 4° C.
= 15·43235 grains.
1 kilogramme, or kilo = 1000 grammes.
= 2·20462 lbs. avoirdupois.
1 gramme = 10 dgms. or decigrammes.
= 100 cgms. or centigrammes.
= 1000 mgms. or milligrammes.
Roughly 15·4 grains = 1 gramme.
65· milligrammes = 1 grain.
454 grammes = 1 lb. avoirdupois.
1 kilo = $2\frac{1}{5}$ lbs.

Mass is not to be confounded with weight. The attraction of the earth acting on the "mass" of a body is recognised by us as its weight. It differs according to the latitude, being about $\frac{1}{2}$ per cent. less at the Equator than at the Poles. The "mass" remains the same, but the acceleration of gravity varies with the place. The importance of the distinction will be seen farther on.

In physical and electrical problems it is now usual to employ the C.G.S. or Centimetre-Gramme-Second system of units.

The centimetre is the unit of *length*, the square centimetre of *area*, and the cubic centimetre of *volume*.

The mean solar second is the unit of *time;* the gramme is the unit of *mass*.

The unit of velocity is *one centimetre per second.*

No change can be effected in the velocity of any body, large or small, without the action of *force*. If stationary, it

will remain stationary; and if moving, it will continue moving in the same direction with the same velocity for ever. Friction, which in practice always puts an end to motion, may be regarded as a *retarding force.* The unit of force is called the "*dyne.*" A dyne, acting for one second on a mass of one gramme, in a state of rest, would cause it to move slowly at first, and gradually faster, until, at the end of the second, its velocity would be exactly at the rate of 1 cm. per second. This increase of velocity is called *acceleration.* Each dyne produces for each second that it acts an acceleration or increase of velocity of one centimetre per second, so that at the end of 3 seconds the velocity of the gramme mass would be 3 cms. per second, and it would have travelled $4\frac{1}{2}$ cms.[1] The *force of gravity*[2] = 981 dynes, so that a body allowed to fall freely would at the end of 1 second have a velocity of 981 cms. per second, and would have fallen 490·5 cms. The *unit of work* is the *erg.* It is the work done in pushing a body through a distance of 1 cm. against a force of 1 dyne. Since the force of gravity = 981 dynes, the work of *lifting* 1 *gramme weight* through a height of 1 cm. = 981 ergs. The *energy* of a body is measured by the work it can do—*e.g.*, in descending from a height, or if moving, in being brought to a standstill. Therefore the unit of energy is also the erg. *Heat* is a form of energy. The unit of heat—the *calorie*—is the quantity required to raise the *temperature* of 1 gramme of water from 0° C. to 1° C.

Heat is convertible into work, and *vice versa.* One calorie = 42,000,000 ergs.

[1] *I.E.*, half the final velocity per second, multiplied by the total number of seconds.

[2] At Greenwich = 981·17 dynes.

Power is the rate of doing work.

Electrical Units.—There are two systems of electrical units—the *electrostatic*, founded on the mutual repulsion of two charged bodies at unit distance apart, and the *electro-magnetic*, based on the mutual repulsion of two similar magnetic poles at unit distance apart. As this book does not profess to deal with the problems of electrostatics, and as the practical units are based on the electro-magnetic system, this only will be given here.

A *magnetic pole of unit strength* placed 1 cm. from another similar pole, repels it with a force of 1 dyne.

There is *unit difference of magnetic potential* between two points when 1 erg must be expended to bring a unit pole from one to the other against the magnetic forces.

Unit intensity of field acts on a north-seeking unit pole with a force of 1 dyne.

Unit current is that current which, flowing through a wire 1 cm. long bent into an arc of a circle of 1 cm. radius, would act upon a unit magnetic pole at the centre of the circle with a force of 1 dyne.

Unit electro-motive force is that pressure or difference of potential which must be maintained between the two ends of a conductor, in order that unit current passing through it may perform 1 erg of work per second.

A conductor has *unit resistance* when unit current is produced in it by unit electro-motive force between its ends.

Unit quantity is the flow of unit current for 1 second.

A condenser has *unit capacity* when unit quantity charges it up to unit difference of potential.

These are the theoretical (C.G.S.) units. The following are those in practical use :—

Resistance.

A column of pure mercury at 0° C., 1 sq. mm. in section and 106 cms. long, has a resistance of 1 *legal ohm*, or "Congress Ohm."

The old B. A. ohm was ·9889 legal ohm.

The Siemens Unit (S.U.) employed in Germany is ·954 B. A. ohm.

The ohm = 10^9 (one thousand million) C.G.S. units.

A megohm = a million ohms.

A microhm = one millionth part of an ohm.

Electro-motive Force.

The volt = 10^8 (one hundred million) C.G.S. units.

1 legal volt = 1·0112 B. A. volt.

Current.

The *ampere* = 10^{-1} (one-tenth) of a C.G.S. unit of current, is the current produced by 1 volt through 1 ohm. The milli-ampere = $\frac{1}{1000}$ ampere.

Quantity.

The *coulomb* = 10^{-1} (one-tenth) of a C.G.S. unit of quantity, is the quantity of current given by 1 ampere in 1 second.

Capacity.

The *farad* = 10^{-9} (the thousand-millionth part of a C.G.S. unit of capacity).

The *microfarad* (*M.F.*) = one-millionth part of a farad, and is therefore equal to $\frac{1}{1000}$th part of a C.G.S. unit of capacity.

Power.

The *watt* is the power developed in a circuit when a current of 1 ampere flows through it at a pressure of 1 volt between the two ends. 746 watts = 1 horse-power.

Temperature

Is measured in England by Fahrenheit's thermometer, and on the Continent (as in this book) by the Centigrade scale.

Fahrenheit:	Freezing point of water	= 32° F.
	Boiling point	= 212° F.
Centigrade:	Freezing point of water	= 0° C.
	Boiling point	= 100° C.

To change from Fahrenheit to Centigrade. Subtract 32, divide by 9, and multiply by 5.

To change from Centigrade to Fahrenheit. Divide by 5, multiply by 9, and add 32.

To include the case of temperature below zero, the above rules must be modified as follows :—

$\frac{5}{9}$ths of the distance from 32 F. is the distance from 0° C.
$\frac{9}{5}$ of the distance from 0° C. is the distance from 32 F.
The "absolute zero" on the Centigrade scale is —273° C.

In Reaumur's thermometer—quoted in old books, the freezing point was zero as in the Centigrade or Celsius scale, but the boiling point was 80° R. Therefore 4° R. = 5° C.

TABLE I.

Atomic Weights and Valencies of the more Common Elements.

Symbol.		Name.	Atomic Weight.	Valency.	Chemical Equivalent.
H	=	Hydrogen	1·	1	1
Li	=	Lithium	7·	1	7
Na	=	Sodium	23·	1	23
K	=	Potassium	39·	1	39
Cu	=	Copper	63	2 (cupric)	31·5
		„	„	1 (cuprous)	63·
Ag	=	Silver	108·	1	108
Au	=	Gold	196·	3	65·5
Mg	=	Magnesium	24	2	12·
Ca	=	Calcium	40	2	20·
Zn	=	Zinc	65	2	32·5
Sr	=	Strontium	87	2	43·5
Cd	=	Cadmium	111·6	2	55·8
Ba	=	Barium	136·8	2	68·4
Hg	=	Mercury	200	2 (mercuric)	100·
		„	„	1 (mercurous)	200
B	=	Boron	11·	3	3·6
Al	=	Aluminium	27·3	3	9·1
C	=	Carbon	12·	4	3·
Si	=	Silicon	28·	4	7·

Symbol.	Name.	Atomic Weight.	Valency.	Chemical Equivalent.
Sn =	Tin	118·	4 (stannic)	29·5
	"	"	2 (stannous)	59·7
Pb =	Lead	206·4	2 (in lead salts)	103·2
N =	Nitrogen	14	3	4·3
P =	Phosphorus	31	3 and 5	...
As =	Arsenic	75	3 and 5	...
Sb =	Antimony	122	3 and 5	...
Bi =	Bismuth	210	...	...
O =	Oxygen	16·	2	8·
S =	Sulphur	32	...	...
Cr =	Chromium	52·4	...	...
F =	Fluorine	19·	1	19·
Cl =	Chlorine	35·5	1	35·5
Br =	Bromine	80·	1	80·
I =	Iodine	127·	1	127·
Mn =	Manganese	54·8	...	...
Fe =	Iron	56·	3 (Ferric)	18·6
	"	"	2 (Ferrous)	28·
Co =	Cobalt	58·6	2	29·3
Ni =	Nickel	58·6	2	29·3

NOTES.—The atomic weights are here given in round numbers, for the sake of simplicity. By means of them the student can ascertain what percentage of each element is contained in any compound of which the formula is given. Thus, blue vitriol, or crystallised copper sulphate, is—

$$CuSO_4 + 5H_2O$$

Whence

$$\begin{aligned} Cu &= 63 \\ S &= 32 \\ O_4 &= 64 \\ 5(H_2O) &= \underline{90} \\ & \quad 249 \end{aligned}$$

Therefore, in 249 grammes of the crystals, there are 63 grammes of copper. Copper sulphate is a *cupric* salt. Calomel is mercurous chloride. Corrosive sublimate is mercuric chloride. Iron proto sulphate (green vitriol) is a ferrous salt, but iron perchloride (*e.g.*, tincture of iron) is a ferric salt.

TABLE II.

Resistance of Copper Wire at 15° C.

New Standard Wire Gauge.

No. S.W.G.	Diameter. Mms.	Resistance. Ohms per Metre.	Weight. Grammes per Metre.
13	2·34	·00406	38·4
16	1·63	·00838	18·6
20	0·914	·0265	5·88
22	0·711	·0438	3·56
24	0·559	·0709	2·19
25	0·508	·0858	1·80
30	0·315	·223	0·697
33	0·254	·343	0·453
36	0·193	·594	0·262
40	0·122	1·49	0·104

TABLE III.

Resistance of Copper Wire.

Birmingham Wire Gauge.

No. B.W.G.	Diameter. Mms.	Yards to the lb. Bare.	Resistance in Ohms per Mile.
8	4·19	4·05	2·063
12	2·77	9·28	4·727
14	2·11	16·00	8·153
16	1·65	26·1	13·29
18	1·22	47·9	24·38
20	0·914	85·1	43·34
22	0·736	131·1	66·79
24	0·635	176·4	89·86
26	0·482	305·5	155·6
28	0·406	430·8	219·4
30	0·355	562·7	286·6
32	0·305	765·9	390·1
34	0·254	1102·0	561·7
36	0·200	1767·0	900·0
40	0·147	3278·0	1670·0

TABLE IV.

Silk-covered German Silver Wire for Resistance Coils, etc.

No. B.W.G.	Diameter. Mms.	Yards per lb. Approximate.	Resistance per lb. Approximate.
8	4·19	4·0	0·0617
12	2·77	9·1	0·3237
16	1·65	25·5	2·562
20	·914	83·	27·23
22	·736	129·	64·69
24	·635	173·	117·1
26	·482	300·	351·1
28	·406	418·	698·3
30	·355	540	1191·
32	·305	73·4	2207·
34	·254	1040	4575·
36	·200	1650	11745·
38	·167	2280	24110·
40	·147	2850	40425·

Note.—English measures are given here, because the wire is sold by the lb.

TABLE V.

Resistance of Various Substances at 0° C.

Elements.

Name.	Cubic Centimetre in Microhms.	Wire 1 Metre long by 1 Mm. diam. in Ohms.	Variation per cent. for 1° C. at 20° C.
Copper, soft	1·598	·02034	0·388
„ hard	1·634	·02081	...
Silver, soft	1·504	·01916	0·377
„ hard	1·634	·02080	...
Gold, soft	2·058	·02620	0·365
„ hard	2·094	·02668	...
Zinc	5·626	·07163	0·365
Mercury	94·320	1·21100	0.072
Aluminium	2·912	·03710	...
Tin	13·210	·16820	0.365
Lead	19·630	·24980	0·387
Antimony	35·500	·45210	0·389
Bismuth	131·200	1·67000	0·354
Iron, soft	9·716	·12370	0·500
Nickel, soft	12·470	·15879	...
Platinum	9·057	·11530	...

Alloys.

Name.	Cubic Centimetre in Microhms.	Wire 1 Metre long by 1 Mm. diam. in Ohms.	Variation per cent. for 1° C. at 20° C.
Brass	5·740	·07308	...
Gold-Silver (2:1)	10·870	·13840	0·065
Platinum-Silver (1:2)	24·390	·31060	0·031
German Silver	20·930	·26660	0·044
Manganin (Manganese-Nickel-Copper)	47·960	·63344	...

Insulators.

Name.		Cubic Centimetre.	
Glass, at	200° C.	$22·700 \times 10^{15}$	C.G.S. units.
„ „	250° C.	$1·390 \times 10^{15}$	„ „
„ „	300° C.	$·148 \times 10^{15}$	„ „
„ „	400° C.	$·074 \times 10^{15}$	„ „
Guttapercha, at	0° C.	$7·000 \times 10^{24}$	„ „
„	at 24° C.	$·353 \times 10^{24}$	„ „
Mica	„ 20° C.	$·084 \times 10^{24}$	„ „
Ebonite	„ 46° C.	$28·000 \times 10^{24}$	„ „
Paraffin	„ 46° C.	$34·000 \times 10^{24}$	„ „

TABLE VI.

Specific Resistance of Electrolytes in C.G.S. units, calculated from Kohlrausch's results.

Zinc Sulphate in Water at 18° *C.*

Strength.	Specific Gravity.	Resistance of 1 Cubic Centimetre.
5 per cent.	1.0509	$5{\cdot}3713 \times 10^{10}$
10 "	1·1069	$3{\cdot}1942 \times 10^{10}$
15 "	1·1675	$2{\cdot}4716 \times 10^{10}$
20 "	1·2323	$2{\cdot}1850 \times 10^{10}$
25 "	1·3045	$2{\cdot}1366 \times 10^{10}$

Copper Sulphate in Water at 18° *C.*

Strength.	Specific Gravity.	Resistance of 1 Cubic Centimetre.
5 per cent.	1·0513	$5{\cdot}4320 \times 10^{10}$
10 "	1·1073	$3{\cdot}2050 \times 10^{10}$
15 "	1·1675	$2{\cdot}4341 \times 10^{10}$

Sulphuric Acid and Water at 18° *C.*

Strength.	Specific Gravity.	Resistance of 1 Cubic Centimetre.
5 per cent.	1·0331	$\cdot 4928 \times 10^{10}$
10 "	1·0673	$\cdot 2617 \times 10^{10}$
15 "	1·1036	$\cdot 1891 \times 10^{10}$
20 "	1·1414	$\cdot 1574 \times 10^{10}$
25 "	1·1807	$\cdot 1433 \times 10^{10}$

Note.—The "index notation" is convenient for expressing very large or very small numbers. 10^{10} means the number 1 followed by 10 ciphers. The small figures raised above the line are called the index or exponent. To express any of the above numbers in full, ***move the decimal point as many places to the right as are indicated by the index***—

Thus, $12\cdot5 \times 10^{3} = 12500\cdot$

If the index is negative, move the decimal point ***to the left***—

Thus, $12\cdot5 \times 10^{-3} = \cdot0125$

THE END.

INDEX.

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CONTENTS

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